BAUER & SMITH

Strength of Wire Ropes
Bent around Sheaves

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STRENGTH OF WIRE ROPES BENT AROUND SHEAVES

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FOR THE

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Frank Stanley Bauer and Paul Ardell Smith

ENTITLED Strength of Wire Ropes Bent around Sheaves

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering

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Instructor in Charge.

APPROVED: G. A. Goodenough

Acting HEAD OF DEPARTMENT OF Mech. Eng'g.

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STRENGTH OF WIRE ROPES BENT AROUND SHEAVES.

-I-

INTRODUCTION.

(1) OBJECT: The bending stresses induced in wire ropes bent around sheaves has always been considered of great importance, and has always been an important factor in determining the minimum size of sheave for a given size of rope. Various formulae have been deduced by which this stress could be computed for any given set of conditions. While all these formulae give a high value for the stress, they vary widely, thus showing that the exact nature and value of the stresses have not yet been fully determined. Due to this inconsistency of previous theories and investigations, an extensive series of tests were carried on at the University of Illinois under the auspices of the Mechanical Engineering Department, to determine more fully the extent of these stresses and the effect of bending on the ropes under a static load. The ropes tested in 1911 were 6 x 19 soft iron, and were furnished by the John A. Roebling's Sons Co., of Trenton, New Jersey.

(2) PREVIOUS INVESTIGATIONS: Previous formulae on this subject are as follows:

In 1865 Reuleaux deduced from the two formulae, $M = \frac{SI}{c}$ and $M = \frac{EI}{R}$, a value of the bending stress $S_b = \frac{Ed}{D}$, where

M = bending moment

S_b = bending stress

$\frac{I}{c}$ = section modulus

E = modulus of elasticity

I = moment of inertia

R = radius of bend

D = diameter of bend

d = diameter of single wire

He based his theory on the assumption that each single wire acted as a simple beam in flexure.

(3) Mr. Hewitt of the Trenton Iron Works has proposed the following forumla for the bending stress:

$$S_b = \frac{E\,A}{2.06\frac{R}{d} + c}\text{, where}$$

E = modulus of elasticity

A = aggregate area of the wires in sq. in.

R = radius of bend

d = diameter of single wire

c = a constant depending on the number of wires in the rope.

For a 7 wire rope c = 9.27, d = 1/9 dia. of rope;

for a 19 wire rope c = 15.45, d = 1/15 dia. of rope.

Hewitt's formula in terms of E, d, and D reduces approximately to $S_b = \frac{0.97\ Ed}{D}$.

(4) Josef Hrabak in 1902 proposed a formula which reduces to $\frac{0.44\ E\ d}{D}$.

(5) In 1908 Mr. R. W. Chapman developed a formula which in terms of E, d, and D is: $S_b = \frac{0.81\ E\ d}{D}$.

(6) From the 1910 University of Illinois tests on plow steel rope the bending stress was found to have a value of $\frac{0.15\ E\ d}{D}$.

Formulae 3, 4, and 5 were deduced from the original formulae into terms of E, d, and D by Coleman and Rugg in the 1910 series of tests at the University of Illinois.

(7) Thus it is seen that the bending stress for a given

size rope and sheave varies from $\frac{E\ d}{D}$ to $\frac{0.15\ E\ d}{D}$. It is, then, the primary object of this thesis to determine if possible which of these formulae is correct and to investigate the effect of static loading on the strength of wire ropes bent around sheaves.

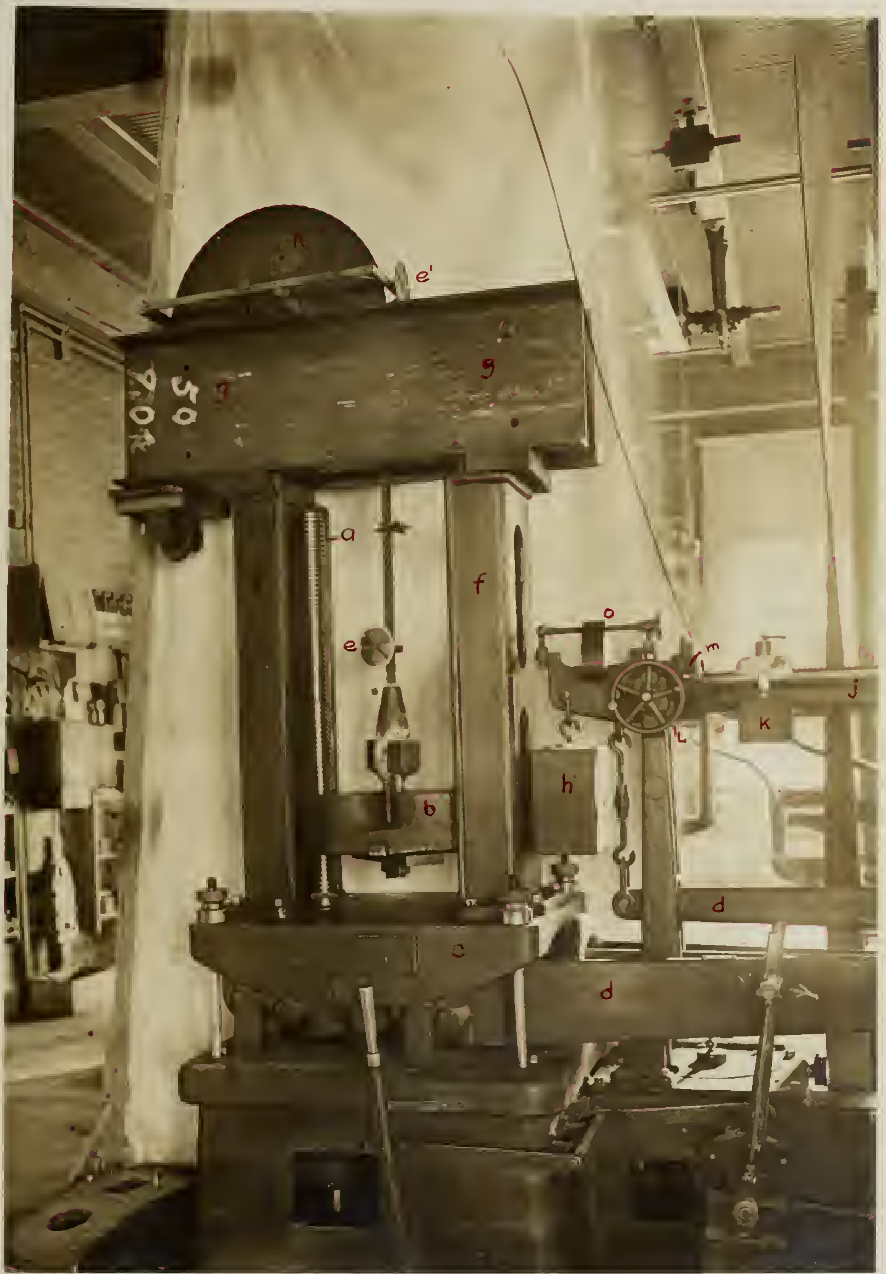


Fig. I

-II-

METHOD OF TESTING.

(8)GENERAL DESCRIPTION: The tests were made in the Laboratory of Applied Mechanics at the University of Illinois under the direct supervision of Professor Herbert F. Moore. Ropes 1/2, 3/4, and 1 inch in diameter were tested to rupture over sheaves 8, 12, 18, and 22 inches in diameter. Also straight pull tests were made of each size of rope and also of the individual wires comprising each size of rope. Duplicate tests were made in all cases, and triplicate tests in most cases.

(9) APPARATUS: The ropes were tested in a standard 100 000 pound testing machine made by the Philadelphia Machine Tool Co., of Philadelphia, Pa. The machine is of the two-screw, power-driven type. The essential features are as follows: In Fig. I (a, a) are the two power-driven screws, by the simultaneous rotation of which the movable head (b) is raised or lowered. The screws pass up through a scale platform (c) which is connected to the scale beam by the levers (d, d). On the platform are the legs (f, f). The fixed head ordinarily rests on the top of these legs, but for this series of tests this head was removed and two 15-inch I-beams (g, g) bolted on in its place. The sheave (h) is placed between these two I-beams and supported by a 4-inch axle (i) which has a flat bearing surface on each beam. The load is determined by balancing the beam (j) with the weight (k) which is moved by a screw in the top of the beam. The screw is rotated by the hand-wheel (L). The scale beam is divided into 100 divisions, thus reading to units of 1000 pounds. The smaller read-

ings are observed in a slot (m) behind which a dial keyed to the screw passes. This dial contains 100 divisions and thus reads to increments of 10 pounds. (n) is a counter-weight, and (o) is a small balancing weight.

(10) MANIPULATION: The general method of procedure was to bend a specimen of the rope around a sheave, applying the load to failure. In this process simultaneous readings were taken of the load, the elongation of the portion of rope over the sheave, and the elongation per unit length on the straight pull portion. The load was observed directly on the scale beam and slot (m), and the elongations over the sheave and the straight pull portions were recorded by the extensometers (e') and (e) respectively. Both extensometer dials were divided into 500 divisions. The circumference of the spindle was one inch. Therefore the instruments read to 1/500 of an inch. In order to obtain a reading from (e') a small wooden frame (p) was pivoted on each side to the ends of the axle (i). The extensometer (e') was screwed into one end, as shown in Fig. I. Small clamps were fastened to the rope just below the sheave. The outside clamp was fastened to the outer end of the wooden frame by a piece of small copper wire. A small weight and a piece of copper wire fastened to the inner clamp and turned several times around the spindle of the extensometer completed the apparatus for obtaining the elongation over the sheave. The readings recorded in the log-book from this instrument are only one-half the actual elongation of the rope over the sheave, since the divisions on the dial were assumed as 1/1000 of an inch for convenience in reading. To obtain the elongation on the straight pull portion, two clamps were fastened

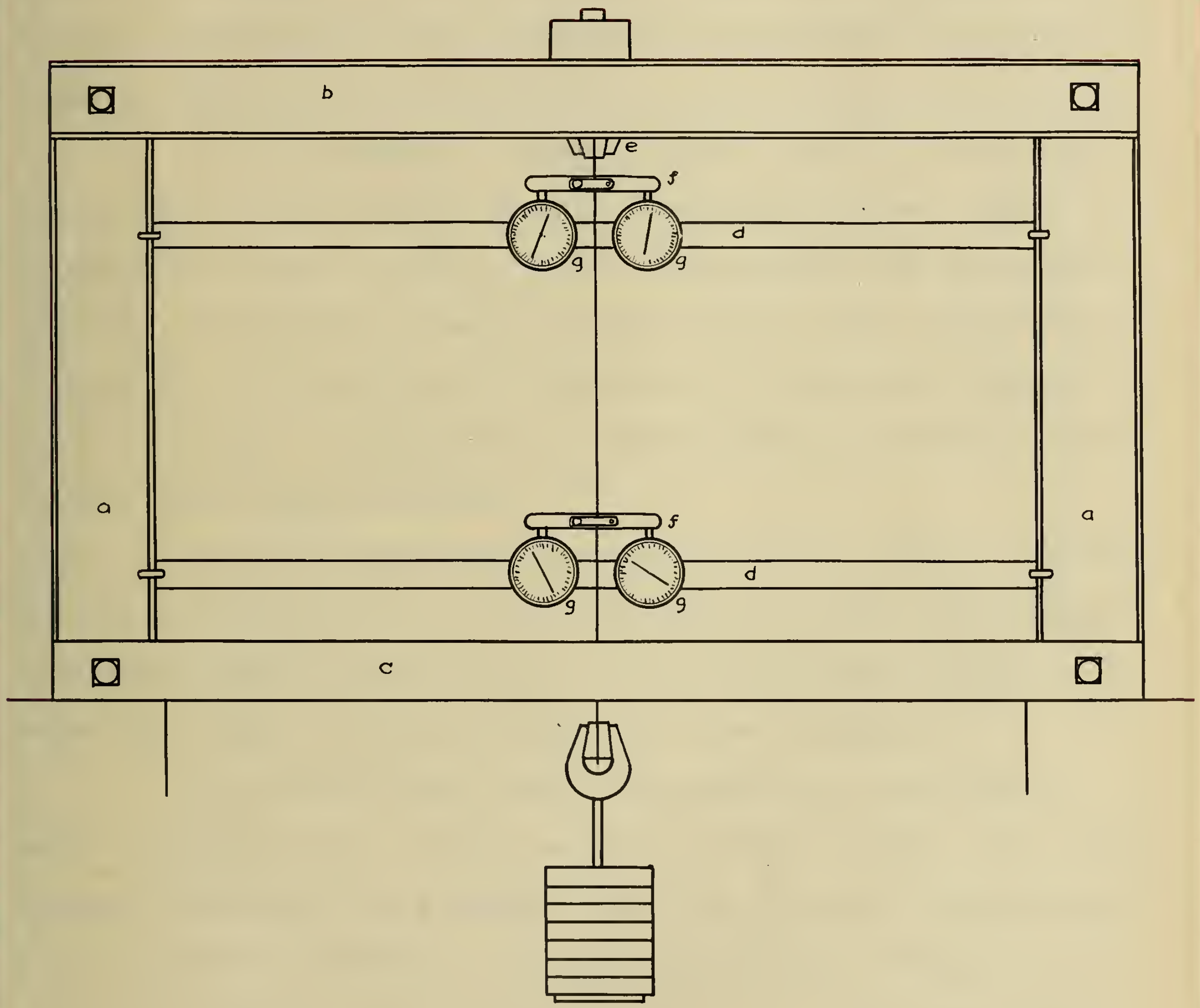


Fig. II

to the rope one foot apart. The extensometer (e) was fastened to the lower clamp. A piece of copper wire with a weight attached was also fastened to this clamp opposite to the extensometer and brought up over three small pulleys on the upper clamp and down around the spindle of the instrument. From this arrangement,the recorded readings were two times the actual elongation between the clamps.

(11) In making a test an initial load of 1 000 pounds was always put on after the machine had been balanced. Then the extensometers were adjusted to zero readings and the load again applied. Simultaneous readings were taken at equal intervals of elongation as recorded by the extensometer giving the elongation over the sheave. Readings were taken at closer intervals as the elastic limit was approached.

(12) The ropes were fastened into the sockets by passing the end through the conical-shaped hole, bending the single wires back, and filling the space with melted babbit metal. The ropes were fastened to the machine as shown in Fig. I.

(13) SINGLE WIRE TESTS: The single wire tests were made on a dead weight testing machine as shown in Fig. II. This machine consisted to two small I-beams (a, a) about twenty inches long, fastened together at the upper ends by the I-beams (b, b) and at the bottom by the wooden strips (c, c) Two dials (g, g) were fastened to each of two smaller wooden strips (d, d),which could be adjusted to any position up or down on the two upright I-beams. The wire to be tested was held in the upper socket by a wedge grip (e). By the same method the weight platform was fastened to the lower end of the wire. To obtain the elongation

for each load, two small metal bars (f, f) were clamped to the wire eight inches apart. After the initial load was applied, the sliding beams (d, d) were so adjusted that these two metal bars (f, f) rested slightly on the plungers of the instruments as shown. The dial readings were adjusted to zero and the load applied, and corresponding instrument readings taken. The true elongation was found by taking the difference between the average of the two upper dial readings and the average of the two lower dial readings. This process was continued at equal intervals of load until the rupture was approached, when the instruments were removed and the load applied to failure.

All observed data was recorded in a standard log-book.

(14) METHOD OF DETERMINING BENDING STRESSES: The method for finding the bending stress for each test will be as follows: If there is any bending stress at all, then the load that will produce a given stress in the straight pull portion will be greater than the load that will produce the same stress in the portion over the sheave. This follows from the fact that the stress over the sheave is made up of the sum of the bending stress S_b and the tensile stress S_t, which is the load applied; while the stress in the straight pull portion is simply that due to the load. Now if the two loads could be determined which produce at different times the same maximum fibre stress in the curved and straight parts of the rope, then their difference would be the bending stress. The stress to be used in determining the two loads will be that at the elastic limit. The load-elongation curve for each portion of the rope can be plotted from the data obtained, and from these curves the loads at the elastic limit can be found. The elastic

limit is assumed as a point on the curve where the rate of deformation is 50 percent greater than that in which the elongation varies directly with the load. J. B. Johnson, in his "Materials of Construction", defines this point as the apparent elastic limit.*

* J.B.Johnson, "Materials of Construction" page 18.

IV.

DATA.

The contents of this part are general data and tables showing results obtained from the tests, and also the curves for each test. The values of the elastic limits were taken from the curves through the application of Johnson's construction.

Table I.

Single Wire Tests.

Elastic Limit and Rupture in Pounds and Pounds per Sq.In.

No.	Diam.Wire In.	Area Sq. In.	Elastic Limit. Lb.	Lb./Sq.In.	Rupture. Lb.	Lb./Sq.In.
1	.032	.000804	33.50	41 600	48.75	60 600
2	.032	"	33.90	42 100	53.75	66 800
3	.032	"	35.0	43 500	53.75	66 800
Av.			34.1	42 400	52.08	64 700
1	.047	.00173	----	------	-----	------
2	.047	"	81.20	46 900	158.75	91 750
3	.047	"	86.00	49 700	128.75	74 400
Av.			83.60	48 300	143.75	83 070
1	.065	.003316	166.00	50 100	268.75	81 000
2	.065	"	137.30	41 300	263.75	79 300
3	.065	"	160.00	48 250	268.75	81 000
Av.			154.40	46 550	267.08	80 430

Table II.

Ultimate Load on Ropes in Pounds.

Dia.	No.	Size of Sheave 8"	12"	18"	22"	Straight Pull
1/2"	1	6 140	4 800	5 590		5 980
"	2	6 160	5 940	6 110		6 030
"	3	6 200	6 000	5 870		5 590
	Av.	6 160	5 580	5 860		5 860
3/4"	1	14 040		14 100	14 200	14 470
"	2	11 650		14 290	11 880	14 230
"	3	13 310		14 100	13 700	14 160
	Av.	13 000		14 160	13 260	14 290
1"	1		26 920	27 500	27 220	28 360
"	2		27 040	27 200	27 300	28 700
"	3		26 850	27 380	27 110	25 600
	Av.		26 940	27 360	27 210	27 550

Ultimate in Pounds per Sq. In.

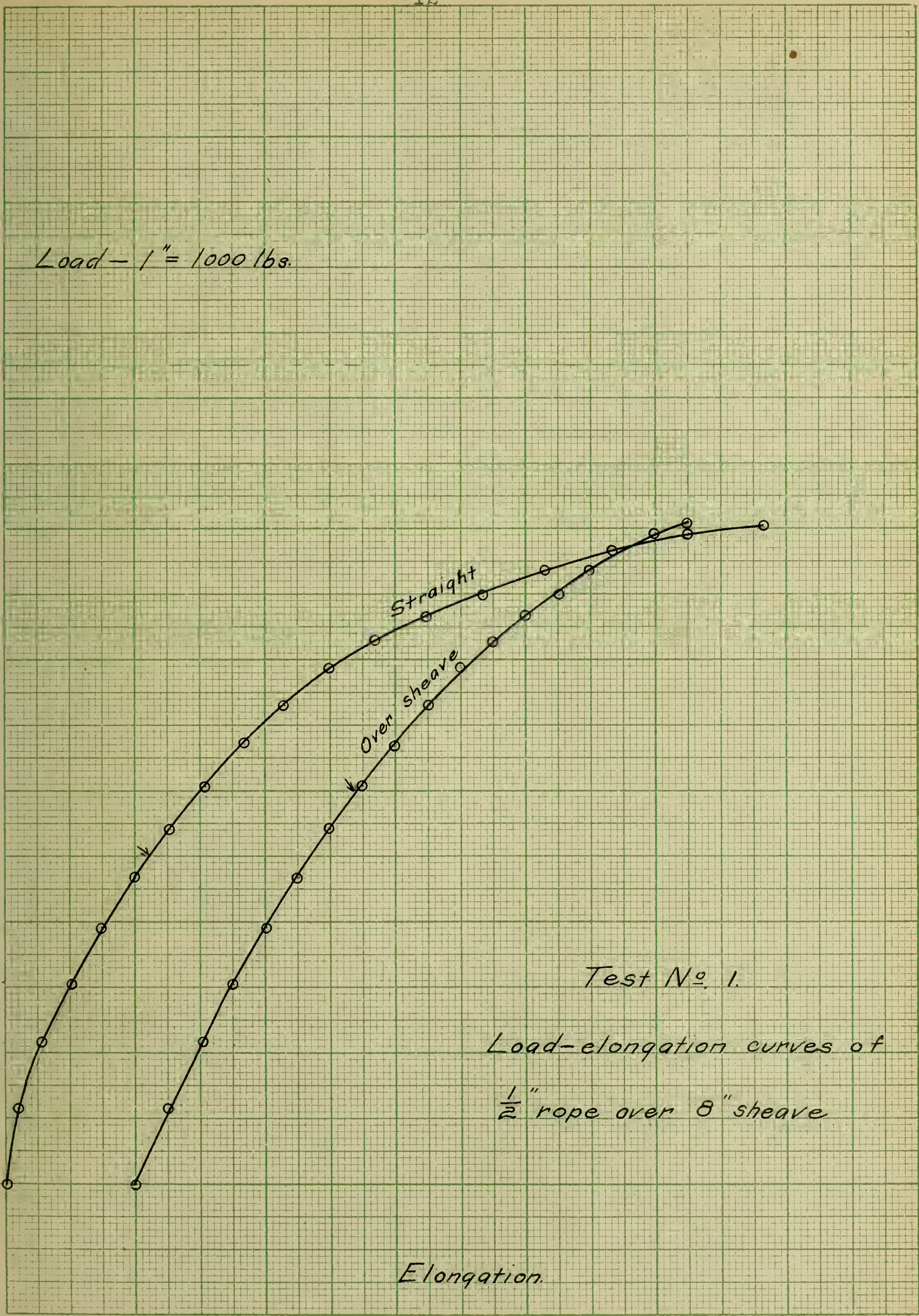
Dia.	No.	8"	12"	18"	22"	Straight Pull
1/2"	1	67 000	52 400	61 000		65 300
"	2	67 300	64 900	66 700		65 800
"	3	67 600	65 400	64 000		61 000
	Av.	67 450	60 900	63 900		64 030
3/4"	1	71 250		71 500	72 000	73 400
"	2	59 100		72 400	60 200	72 300
"	3	67 500		71 500	69 500	71 800
	Av.	65 950		71 800	76 200	72 500
1"	1		71 200	72 800	72 200	75 000
"	2		71 700	72 000	72 300	76 000
"	3		71 100	72 400	71 800	67 500
	Av.		71 330	72 400	72 100	72 930

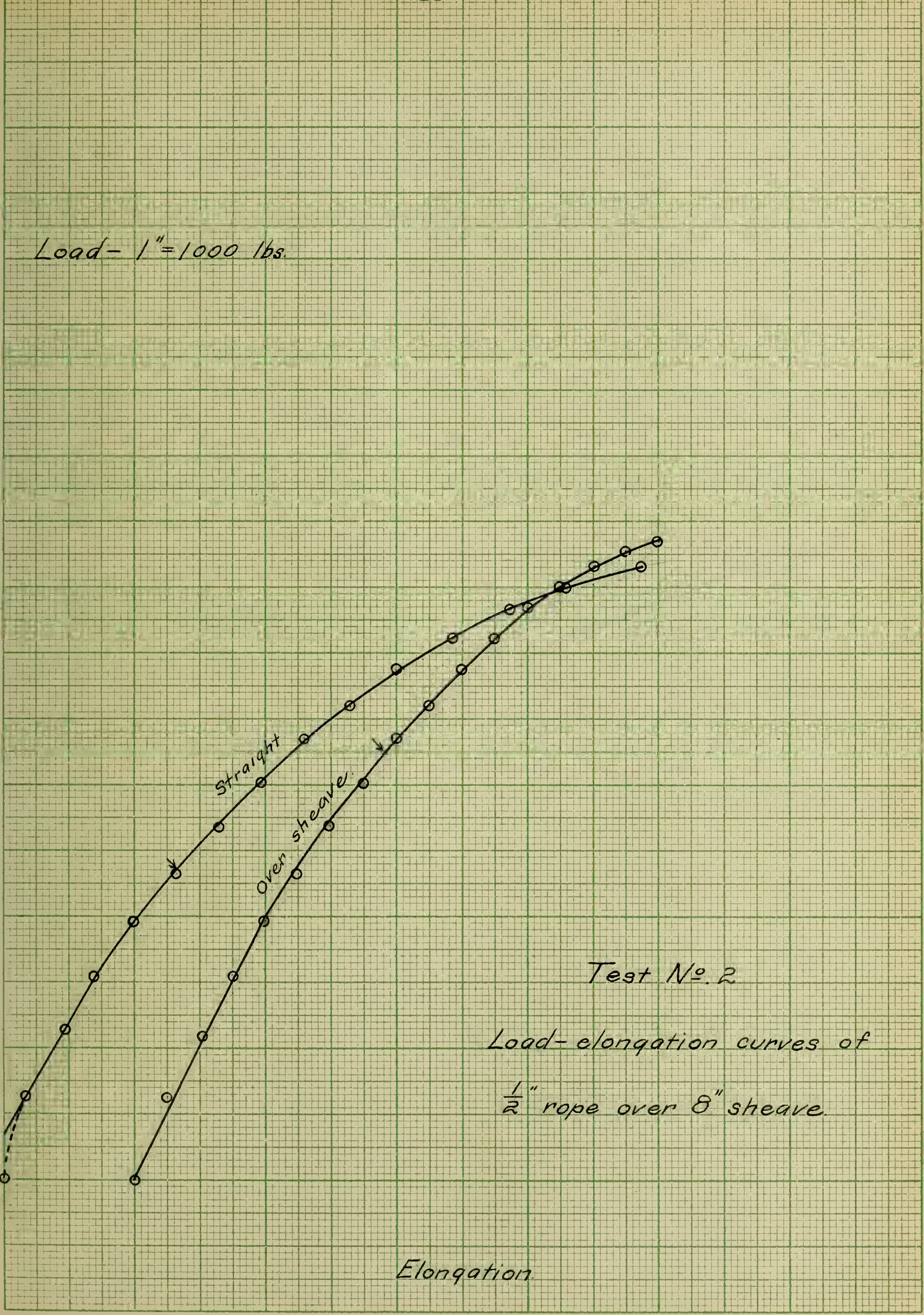
Table III.

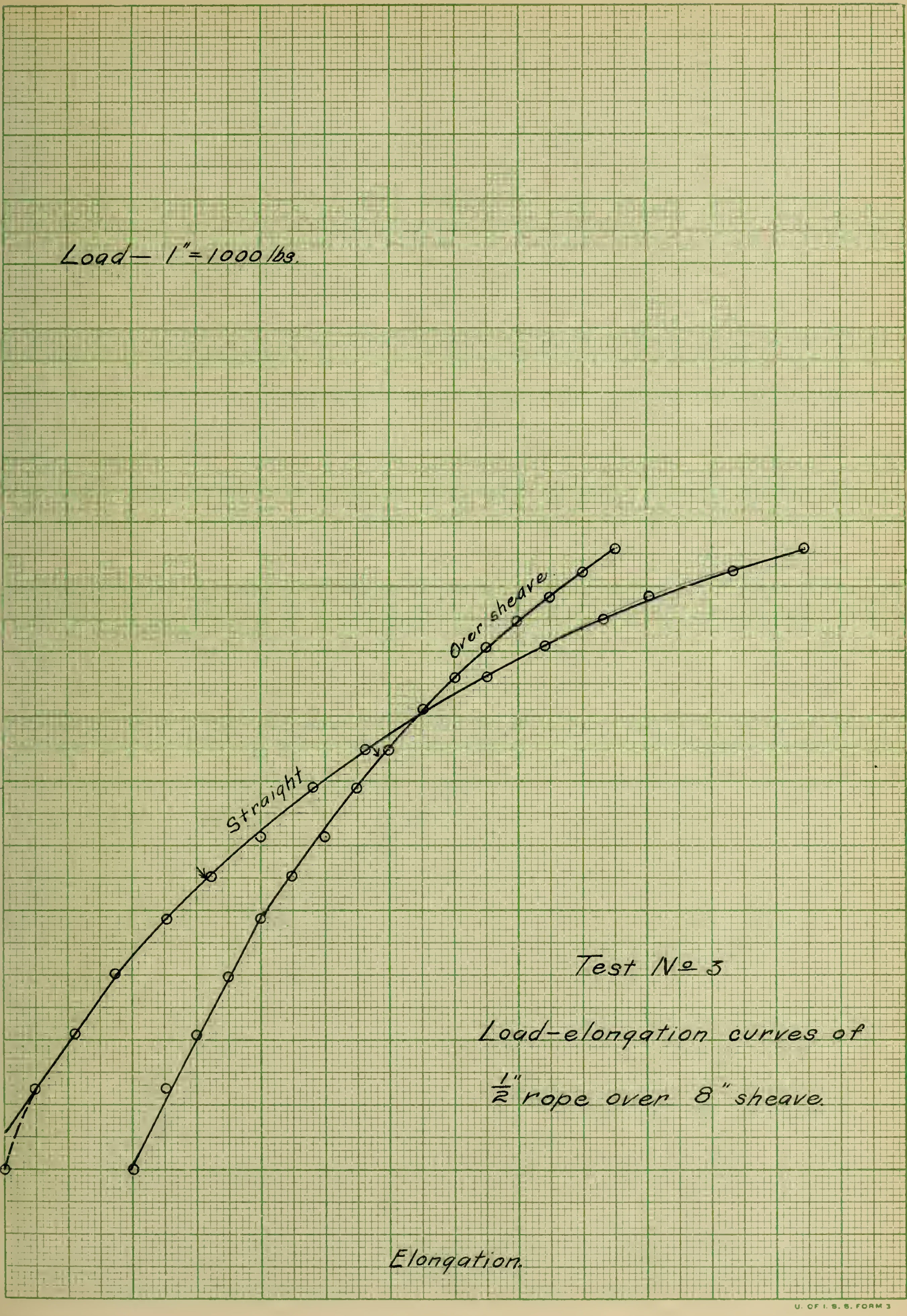
Elastic Limit of Ropes in Pounds.

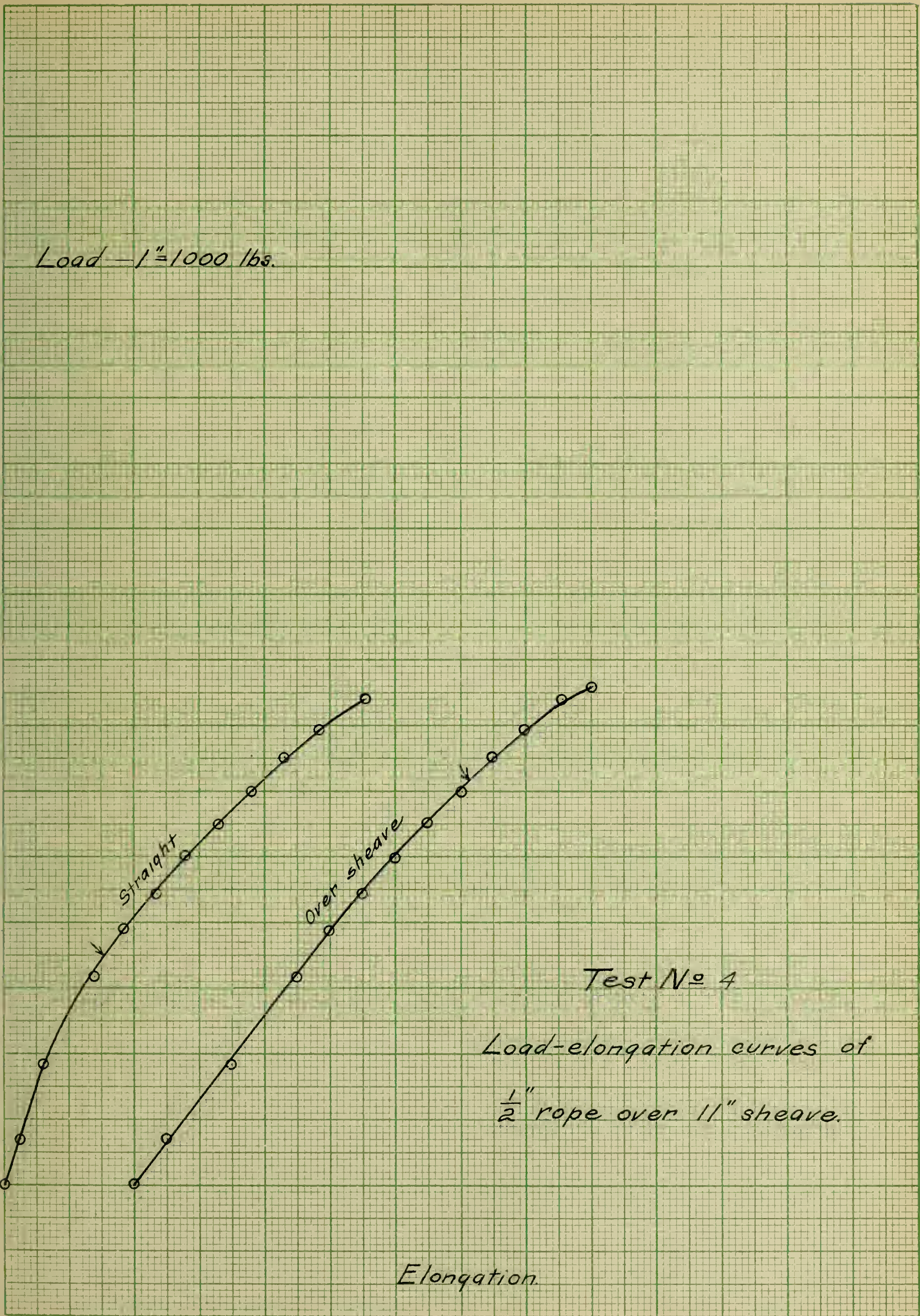
sh = Portion over Sheave, st = straight pull part.

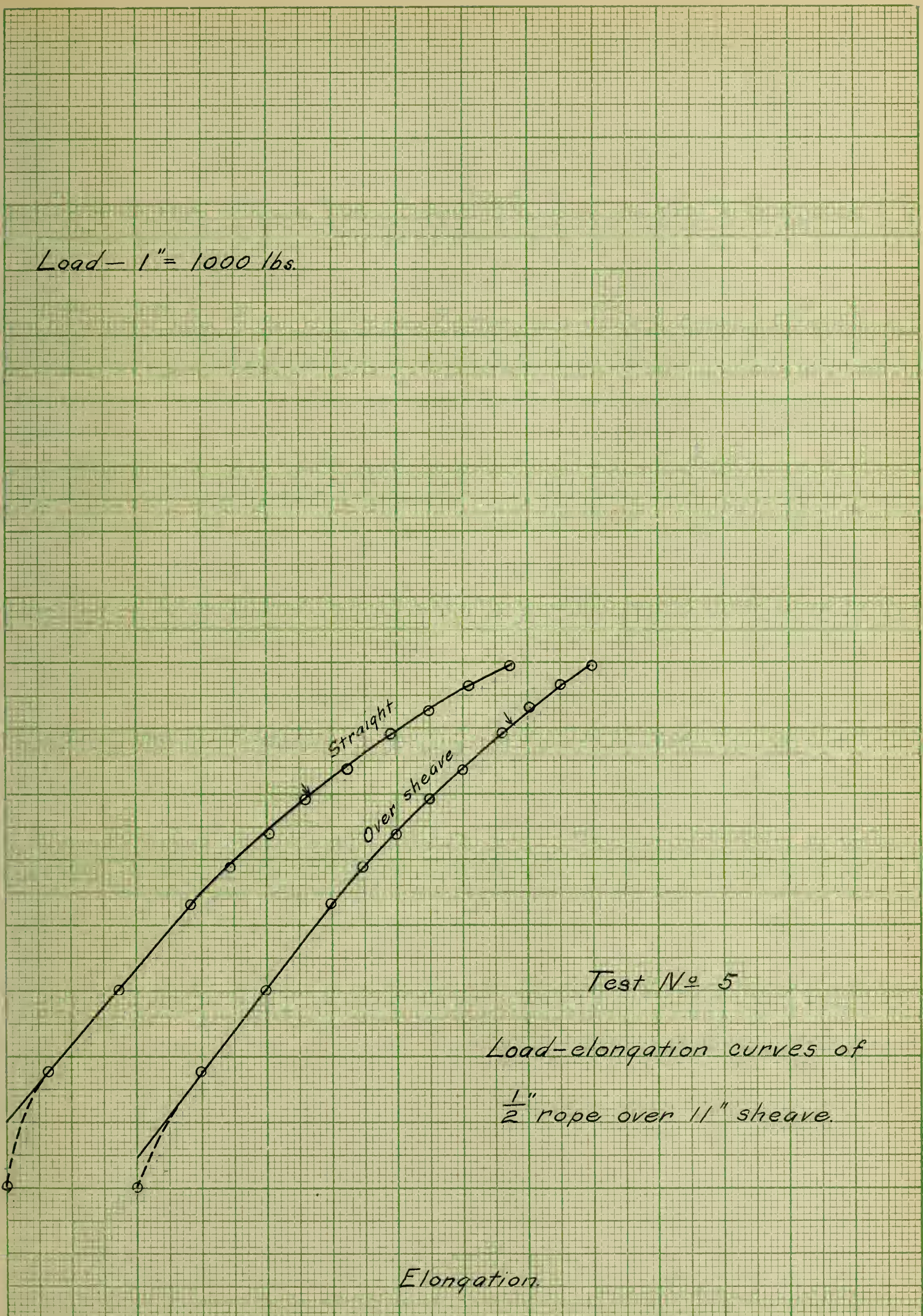
No.	Dia. Rope	8" sh	8" st	12" sh	12" st	18" sh	18" st	22" sh	22" st	Strght. Pull
1	1/2"	4000	3500	4100	2750	3800	3600			2860
2	"	4200	3300	4500	4000	4100	4000			2360
3	"	4200	3250	3800	3700	4200	4000			2640
Av.		4170	3350	4130	3850	4030	3870			2620
1	3/4"	11200	6650			9750	6200	7500	7300	7900
2	"	8950	7900			10750	7300	8200	8000	4450
3	"	9150	7050			9750	9770	9300	7000	5200
Av.		9730	7200			10080	7760	8330	7430	5850
1	1"			21400	14750	19500	16800	19800	18000	15600
2	"			15700	13100	15850	15050	18500	11000	13200
3	"			23000	17250	20100	15550	19200	20800	20600
Av.				20030	15030	18480	15800	19160	16600	16460
				Elastic Limit - Pounds per Sq. In.						
1	1/2"	43700	48200	44700		41500	39300			31200
2	"	45900	36000	49000	43700	44700	43700			25850
3	"	45900	35500	41500	40400	45900	43700			28800
Av.		45170	36570	45070	42050	44030	42230			28620
1	3/4"	56900	33750			49500	31500	38000	37100	40000
2	"	45400	40100			54600	37050	41600	40600	22580
3	"	46500	35800			49500	49600	47100	35500	26380
Av.		49600	36550			51200	39380	42230	37730	29650
1	1"			56600	39000	51600	44400	52400	47700	41300
2	"			41600	34650	41900	39800	49000	29100	35000
3	"			60900	45650	53200	41200	50800	55000	54500
Av.				53030	39770	48900	41800	50730	43930	43630


Load — 1" = 1000 lbs.
Straight
Over sheave
Test No. 1.
Load-elongation curves of
1/2" rope over 8" sheave
Elongation.


Load- 1" = 1000 lbs.
Straight
Over sheave
Test No. 2
Load-elongation curves of
1/2" rope over 8" sheave.
Elongation


Load— 1" = 1000 lbs.
Over sheave.
Straight
Test No 3
Load-elongation curves of
1/2" rope over 8" sheave.
Elongation.

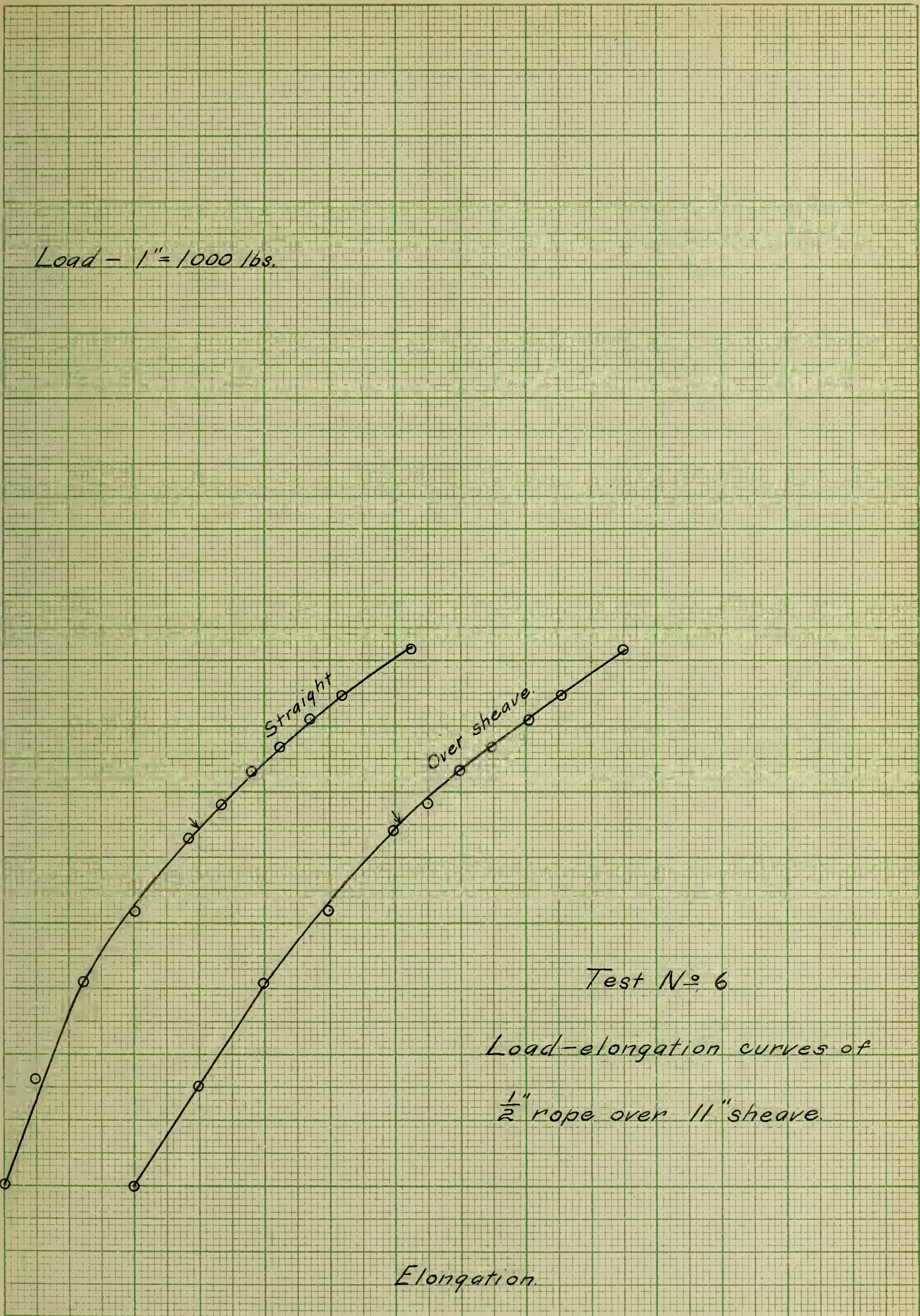

Load — 1" = 1000 lbs.
Straight
Over sheave
Test No 4
Load-elongation curves of
1/2" rope over 11" sheave.
Elongation.

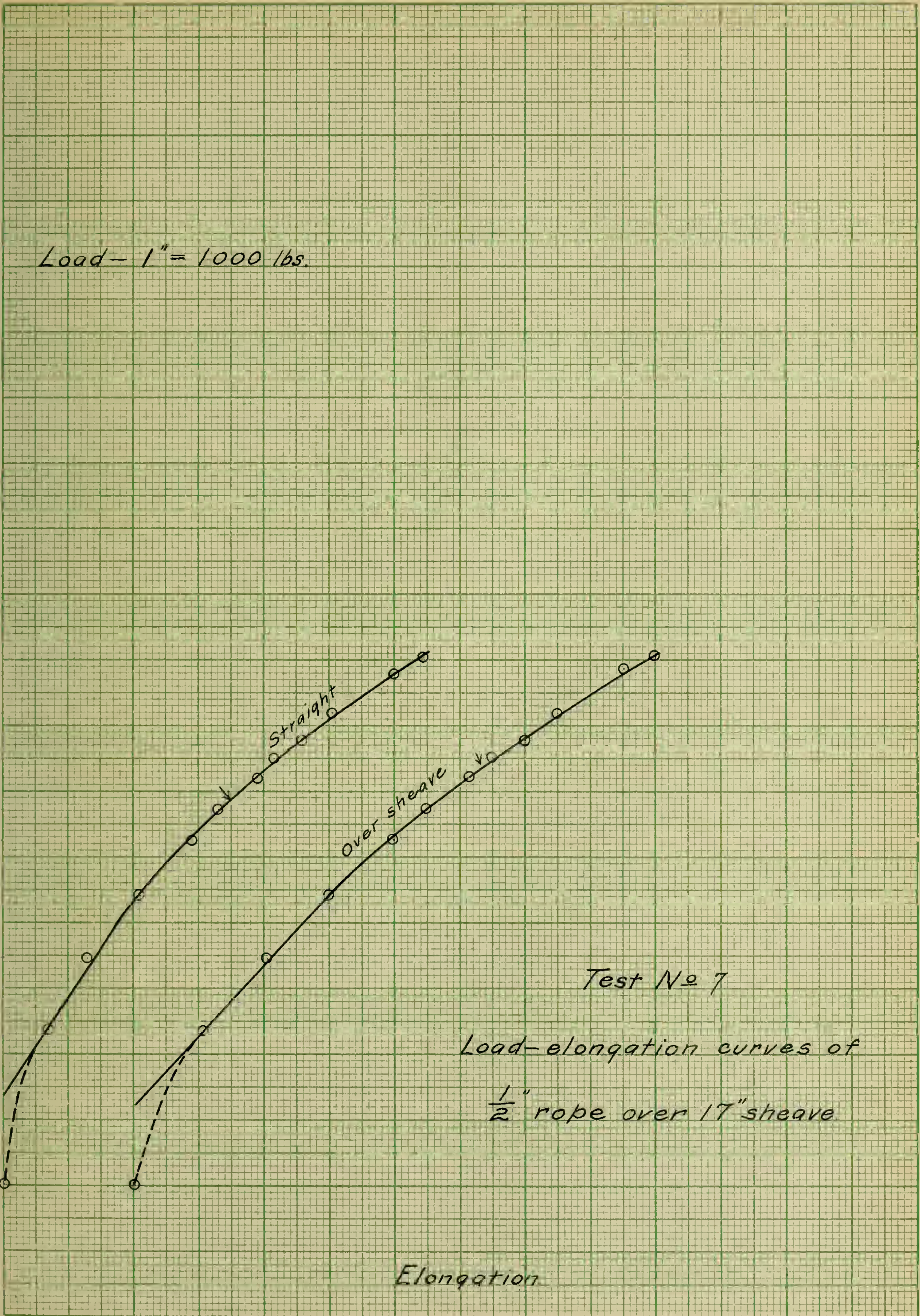


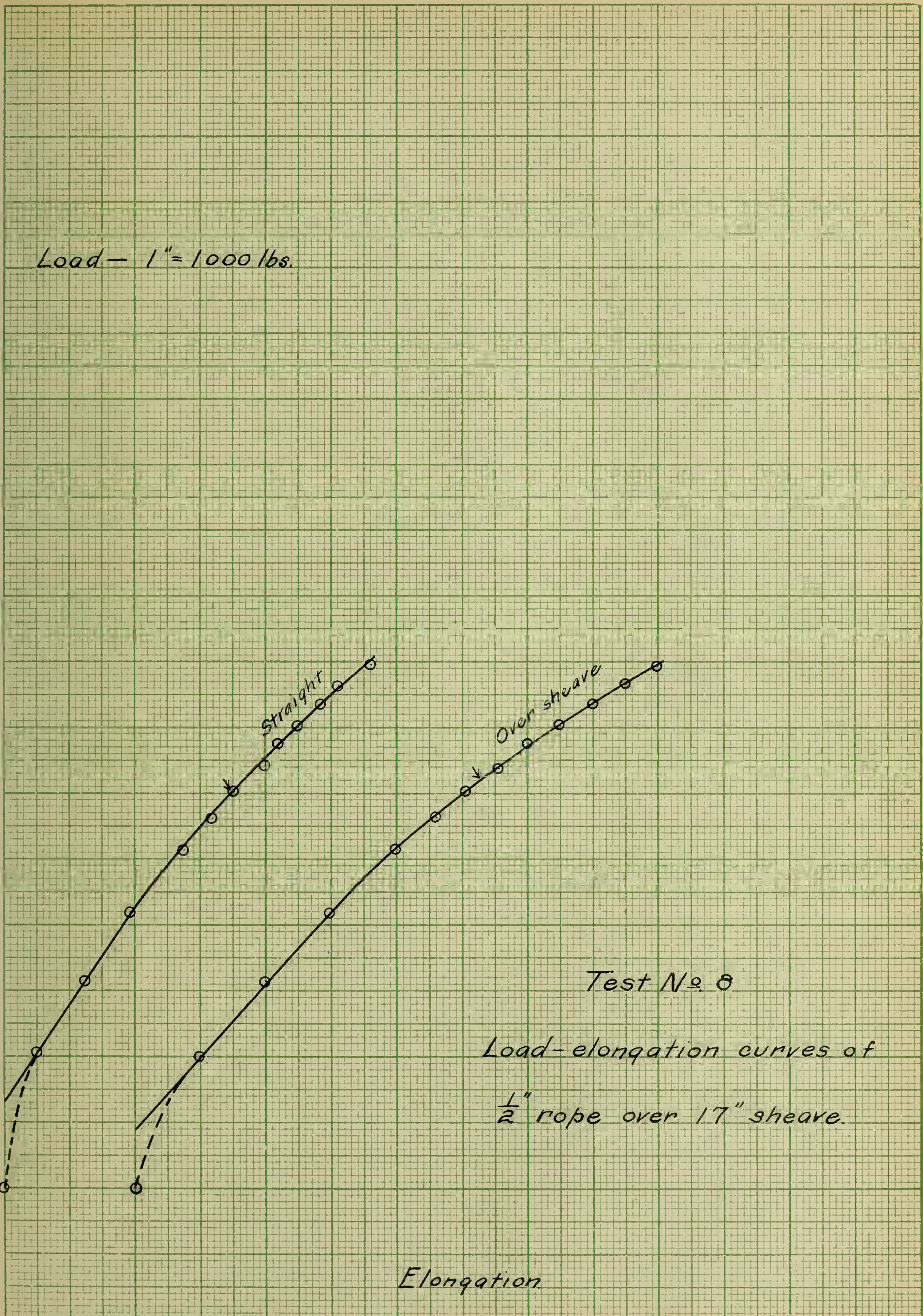
Test No. 5

Load-elongation curves of

$\frac{1}{2}$" rope over 11" sheave.


Load - 1" = 1000 lbs.
Straight
Over sheave
Test No. 6
Load-elongation curves of
$\frac{1}{2}$" rope over 11" sheave.
Elongation

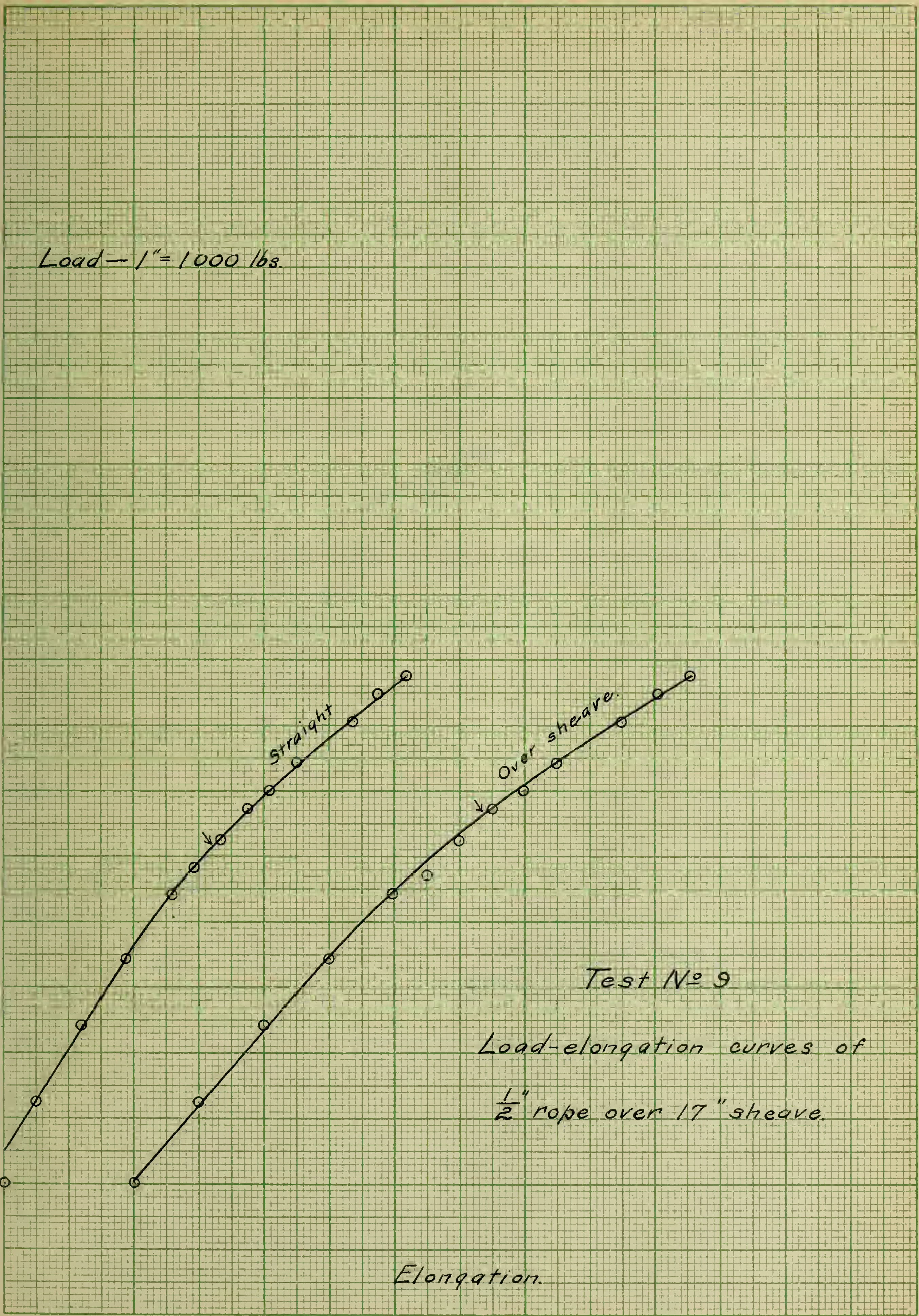

Load – 1" = 1000 lbs.
Straight
Over sheave
Test № 7
Load-elongation curves of
1/2" rope over 17" sheave
Elongation

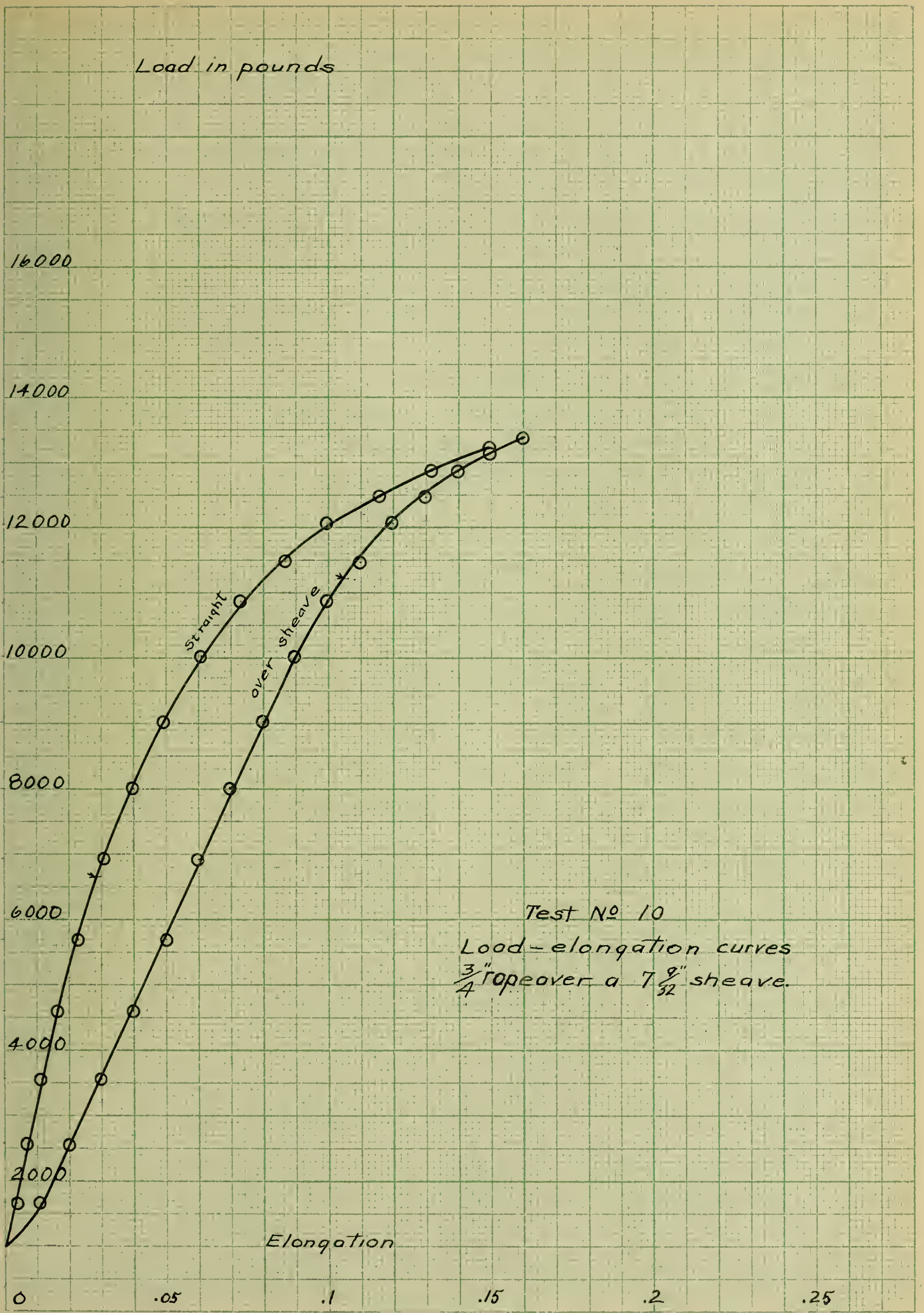


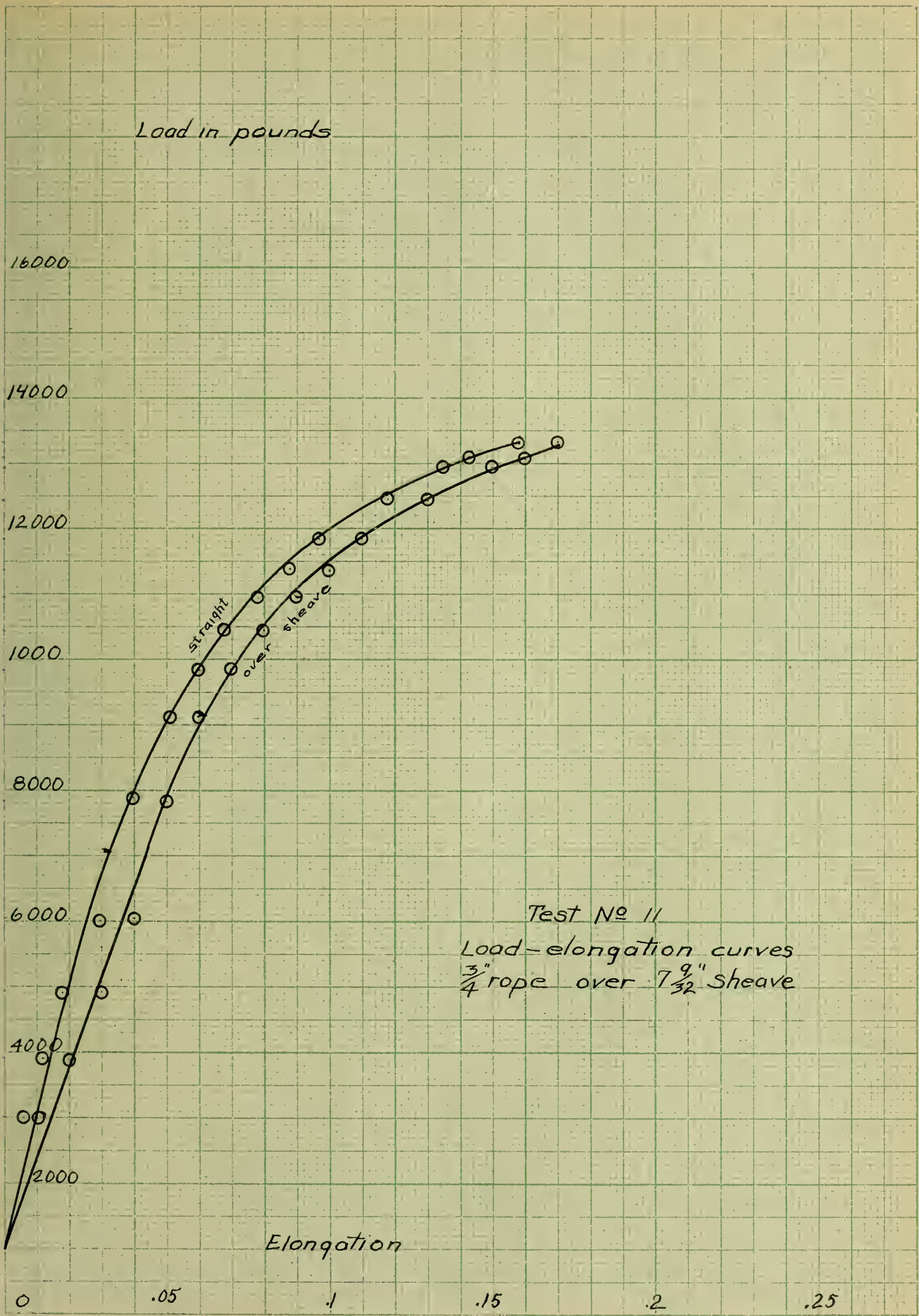
Test № 8

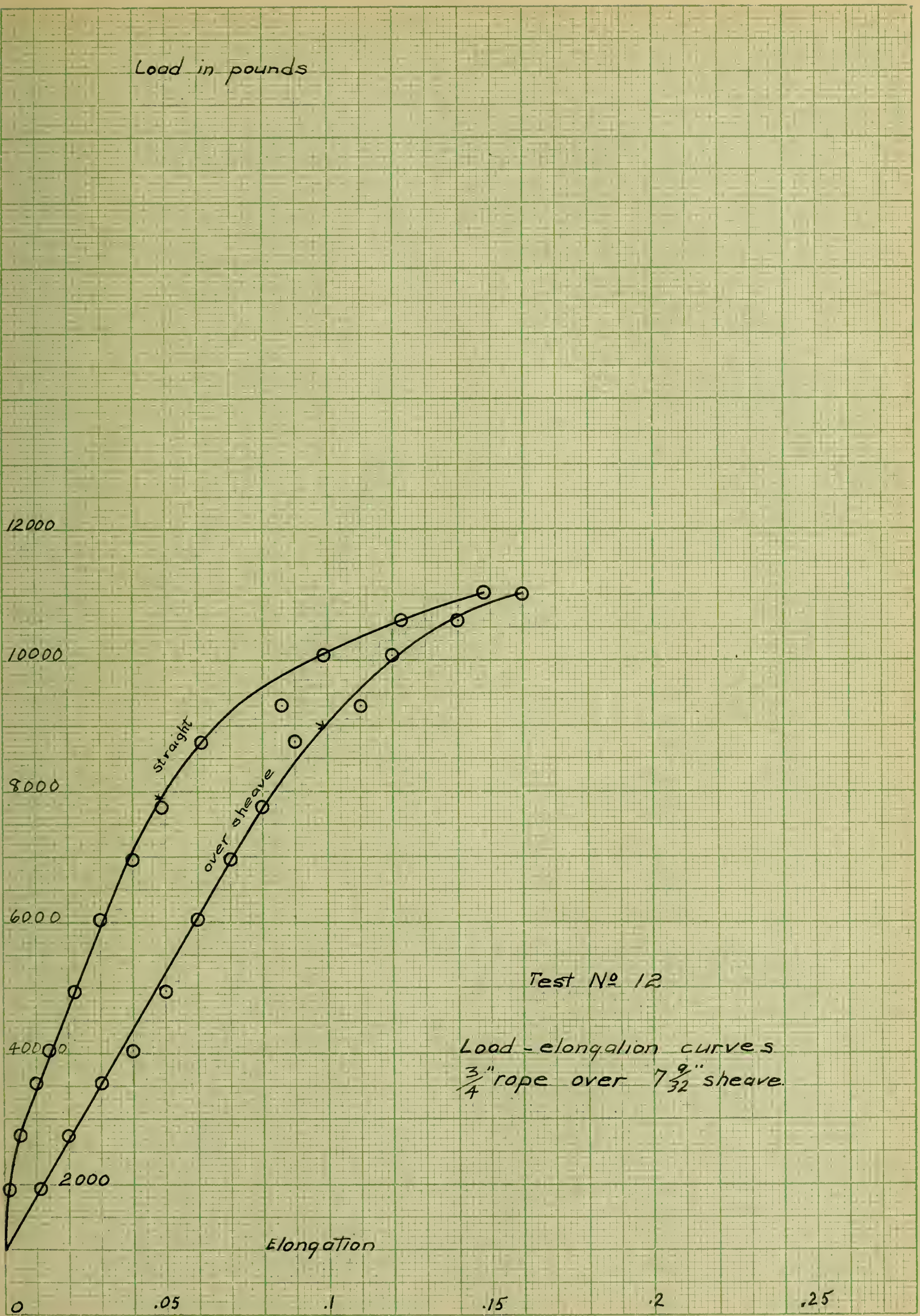
Load-elongation curves of

$\frac{1}{2}$" rope over 17" sheave.


Load — 1" = 1000 lbs.
Straight
Over sheave.
Test № 9
Load-elongation curves of
1/2" rope over 17" sheave.
Elongation.

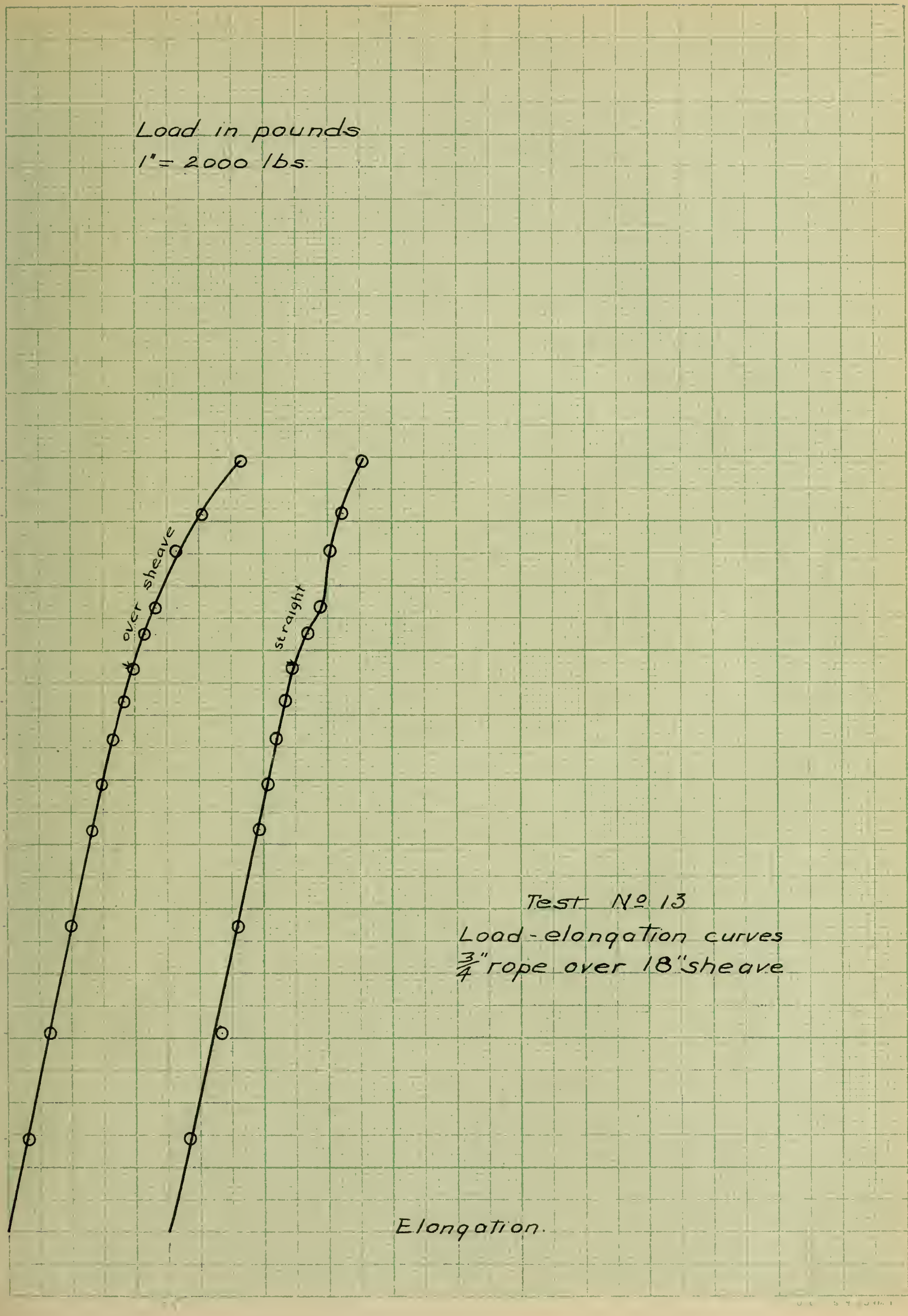

Load in pounds
16000
14000
12000
10000
8000
6000
4000
2000
0
.05
.1
.15
.2
.25
Elongation
Straight
over sheave
Test № 10
Load-elongation curves
3/4" rope over a 7 9/32" sheave.

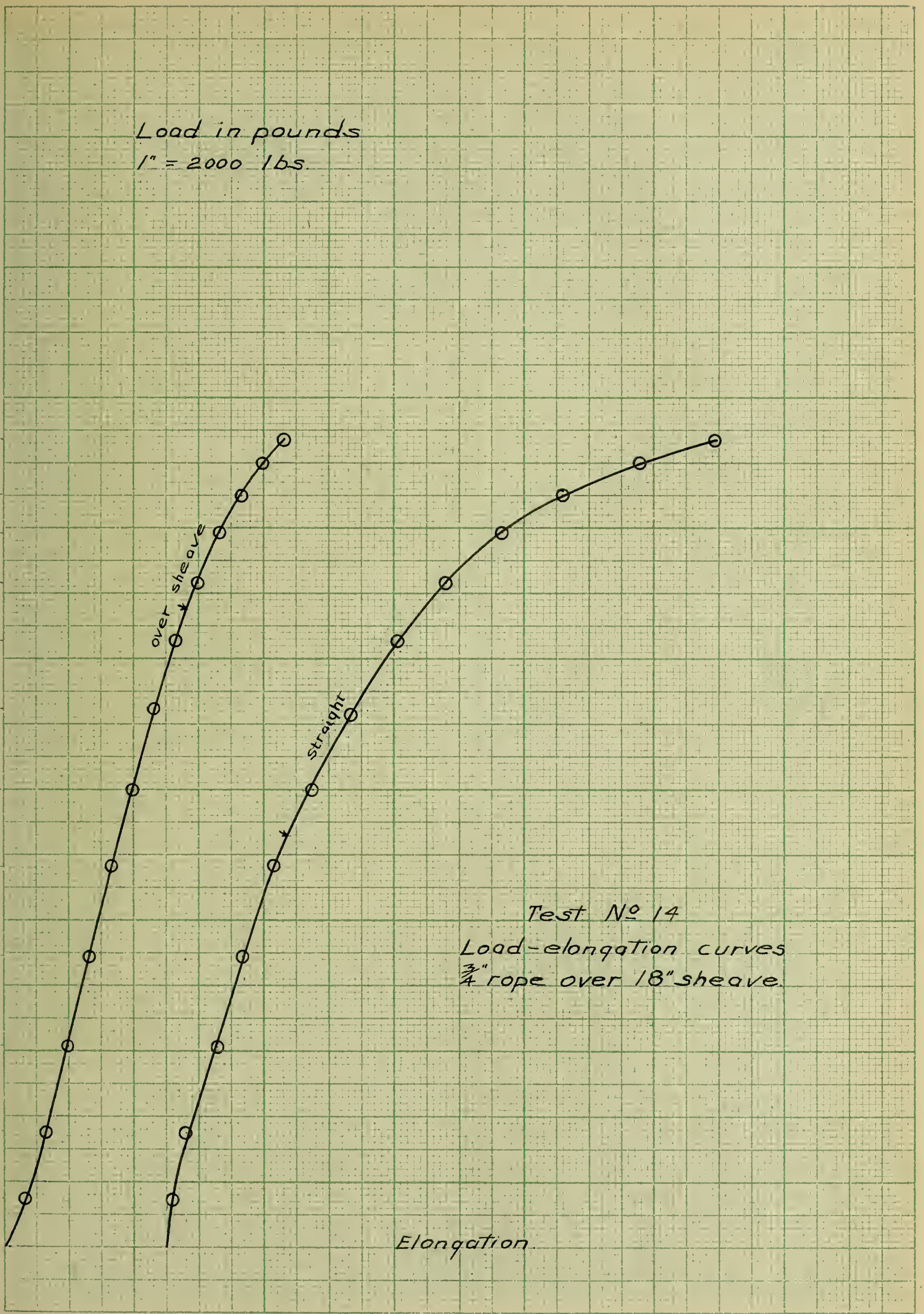

Load in pounds
16000
14000
12000
1000
8000
6000
4000
2000
straight
over sheave
Test № 11
Load-elongation curves
3/4" rope over 7 9/32" Sheave
Elongation
0
.05
.1
.15
.2
.25

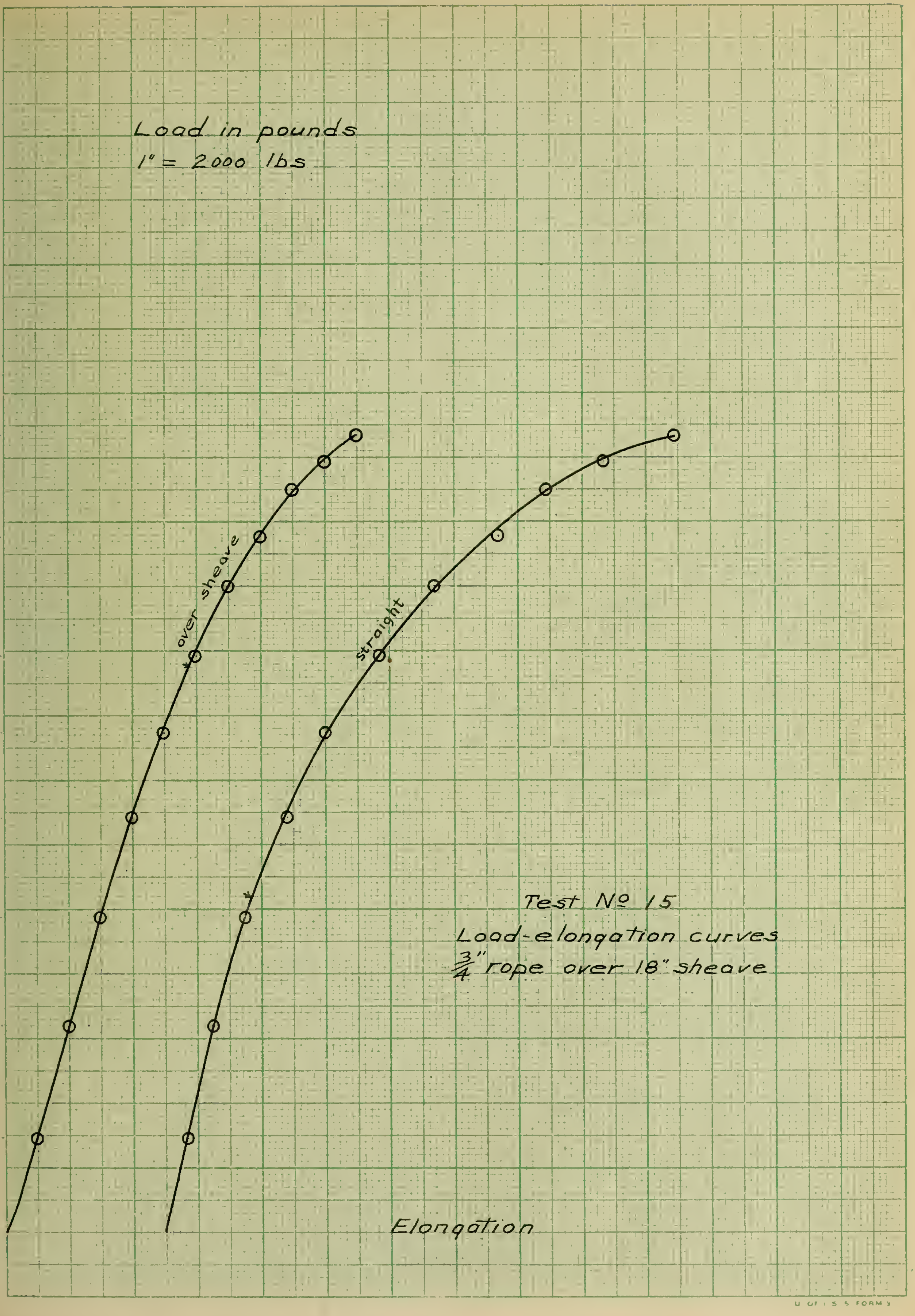


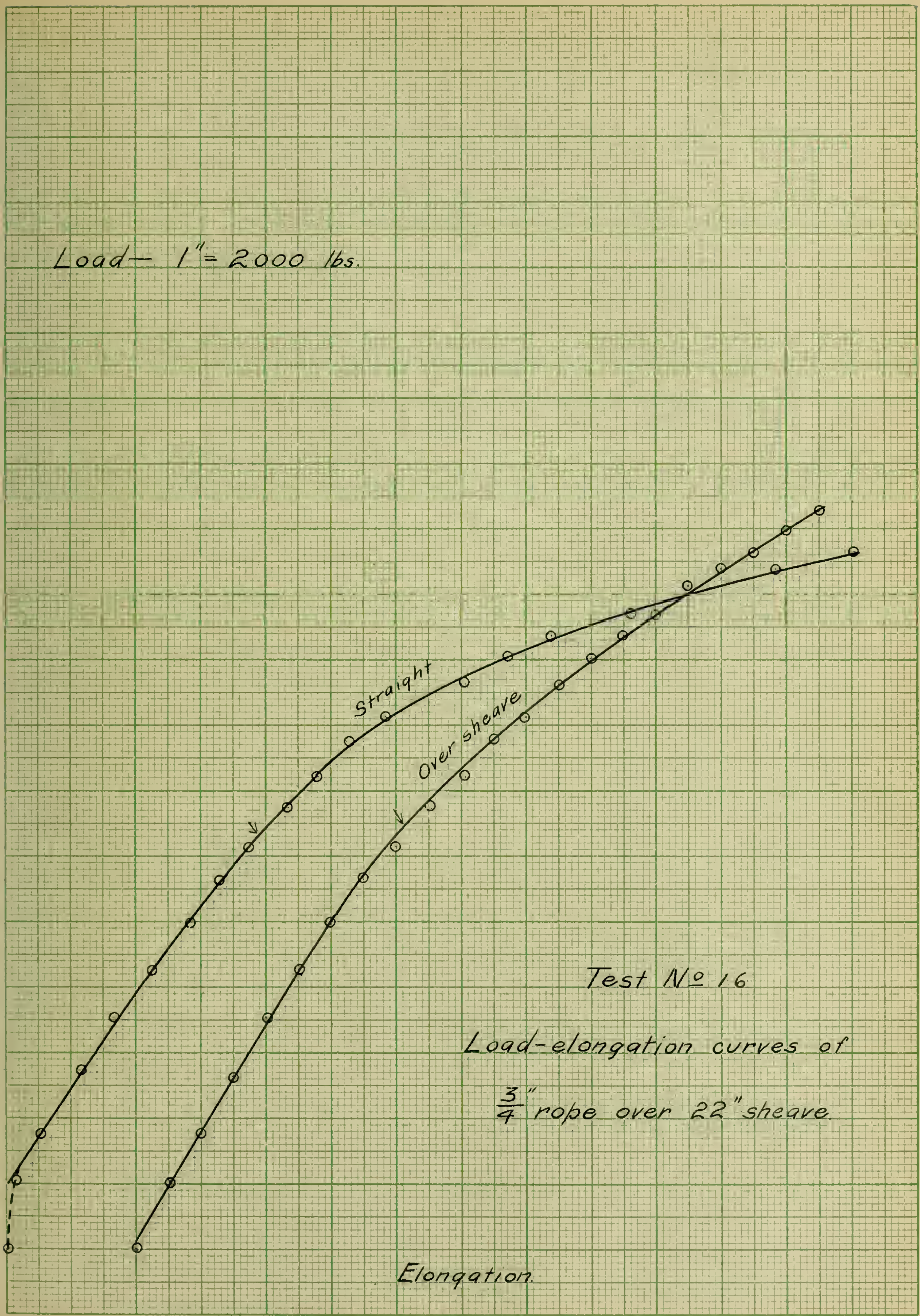
Test № 12

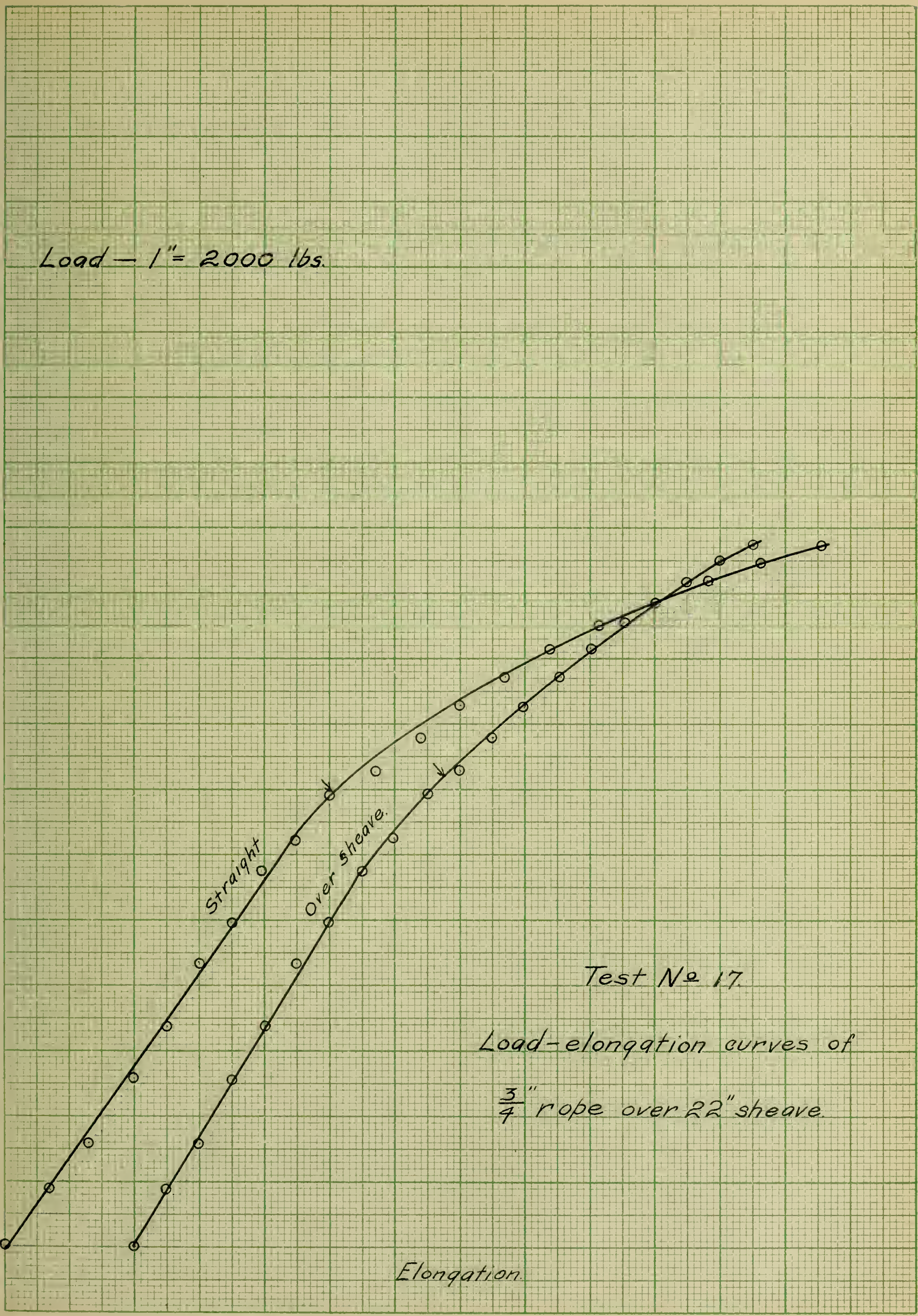
Load - elongation curves
$\frac{3}{4}$" rope over $7\frac{9}{32}$" sheave

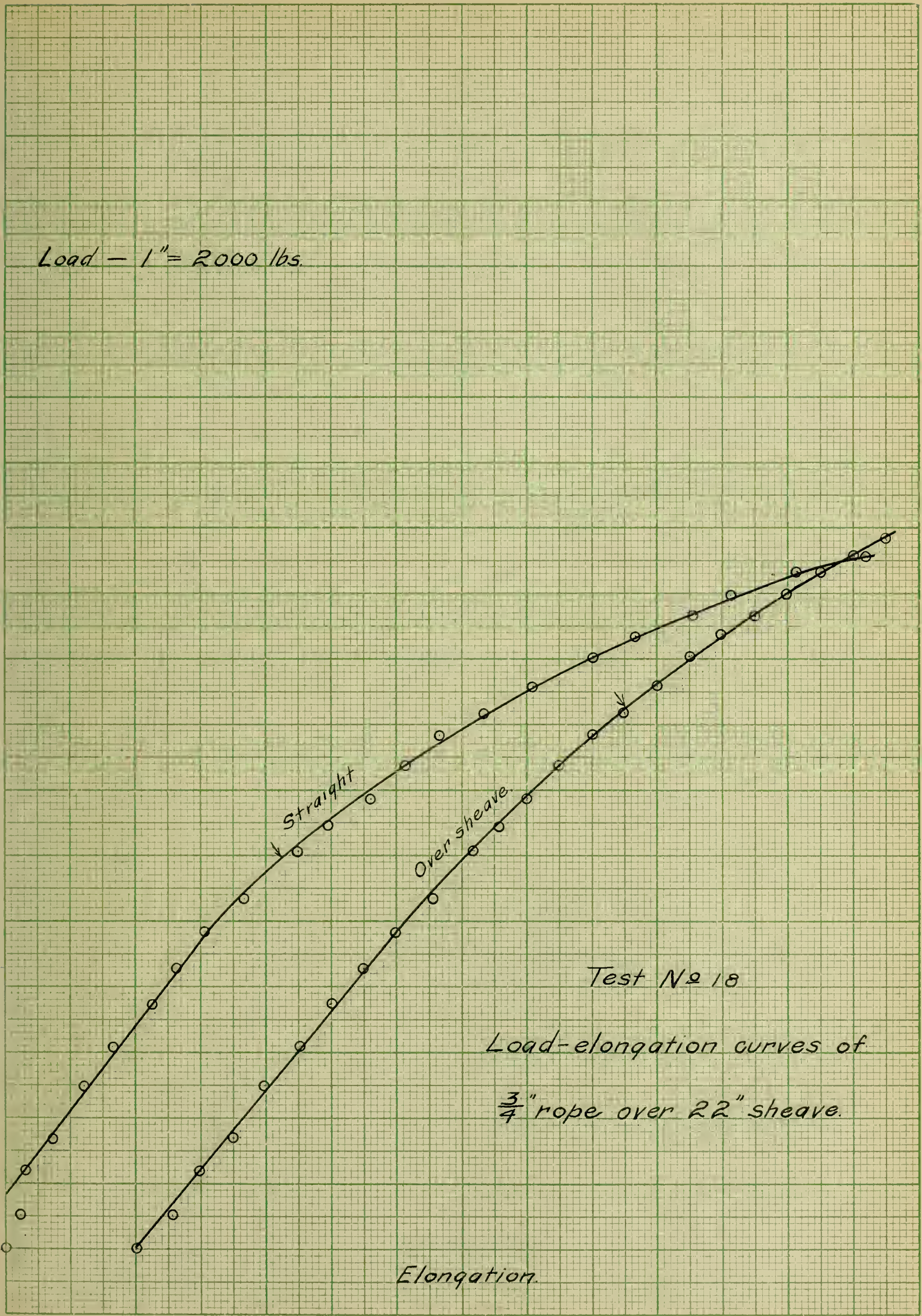

Load in pounds
1" = 2000 lbs.
over sheave
straight
Test No 13
Load-elongation curves
3/4" rope over 18" sheave
Elongation.

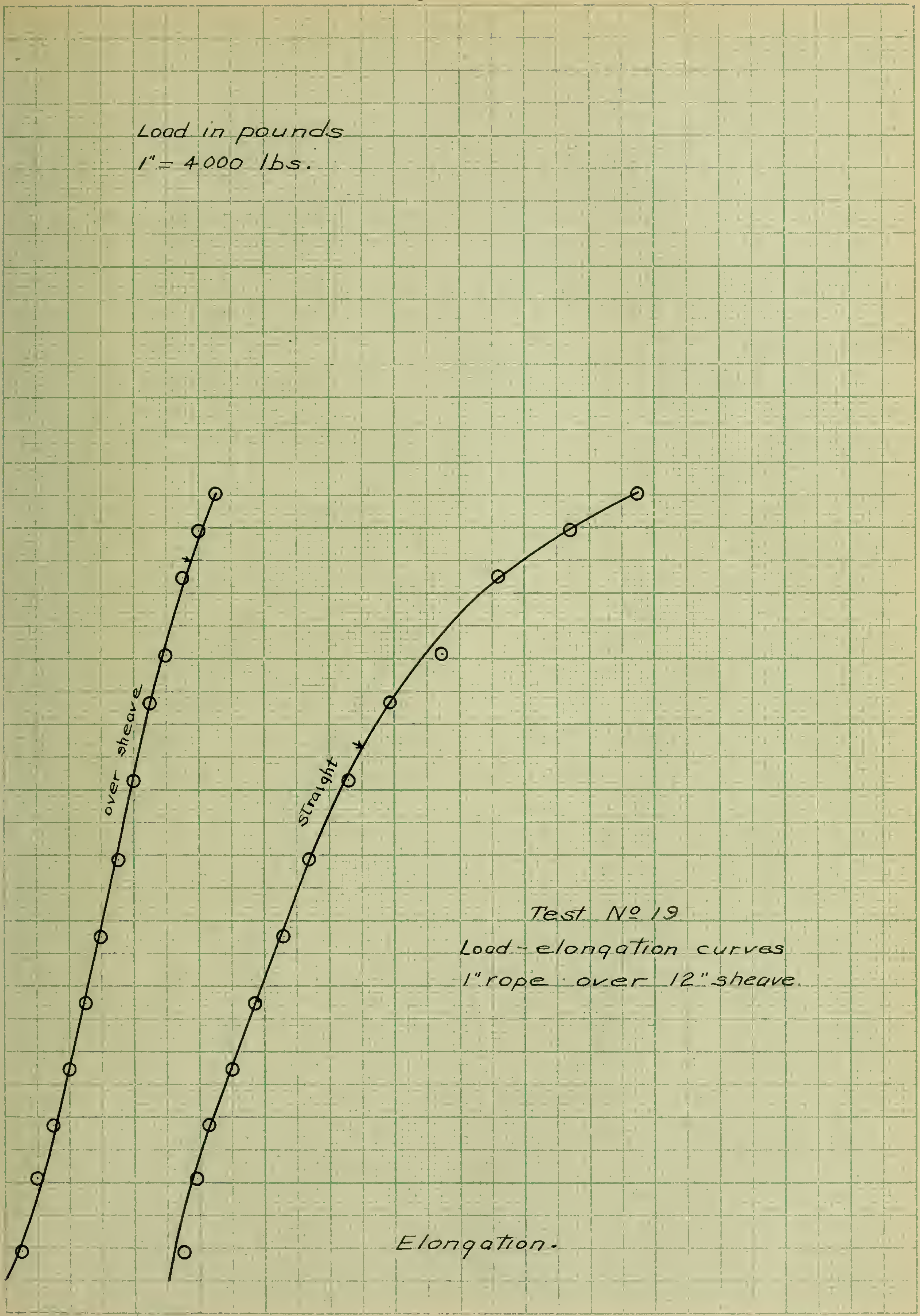

Load in pounds
1" = 2000 lbs.
over sheave
straight
Test No 14
Load-elongation curves
3/4" rope over 18" sheave.
Elongation

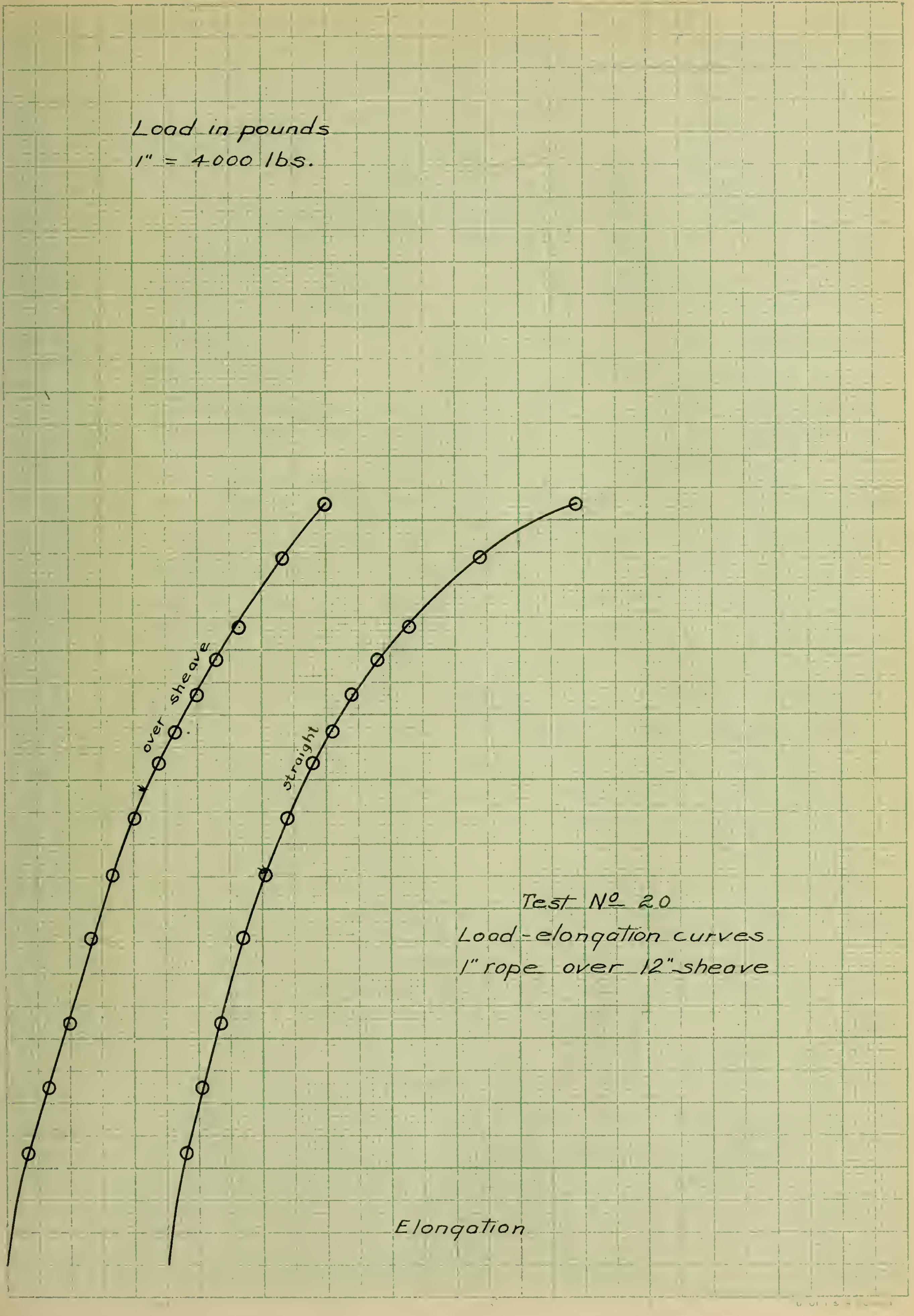

Load in pounds
1" = 2000 lbs
over sheave
straight
Test № 15
Load-elongation curves
3/4" rope over 18" sheave
Elongation

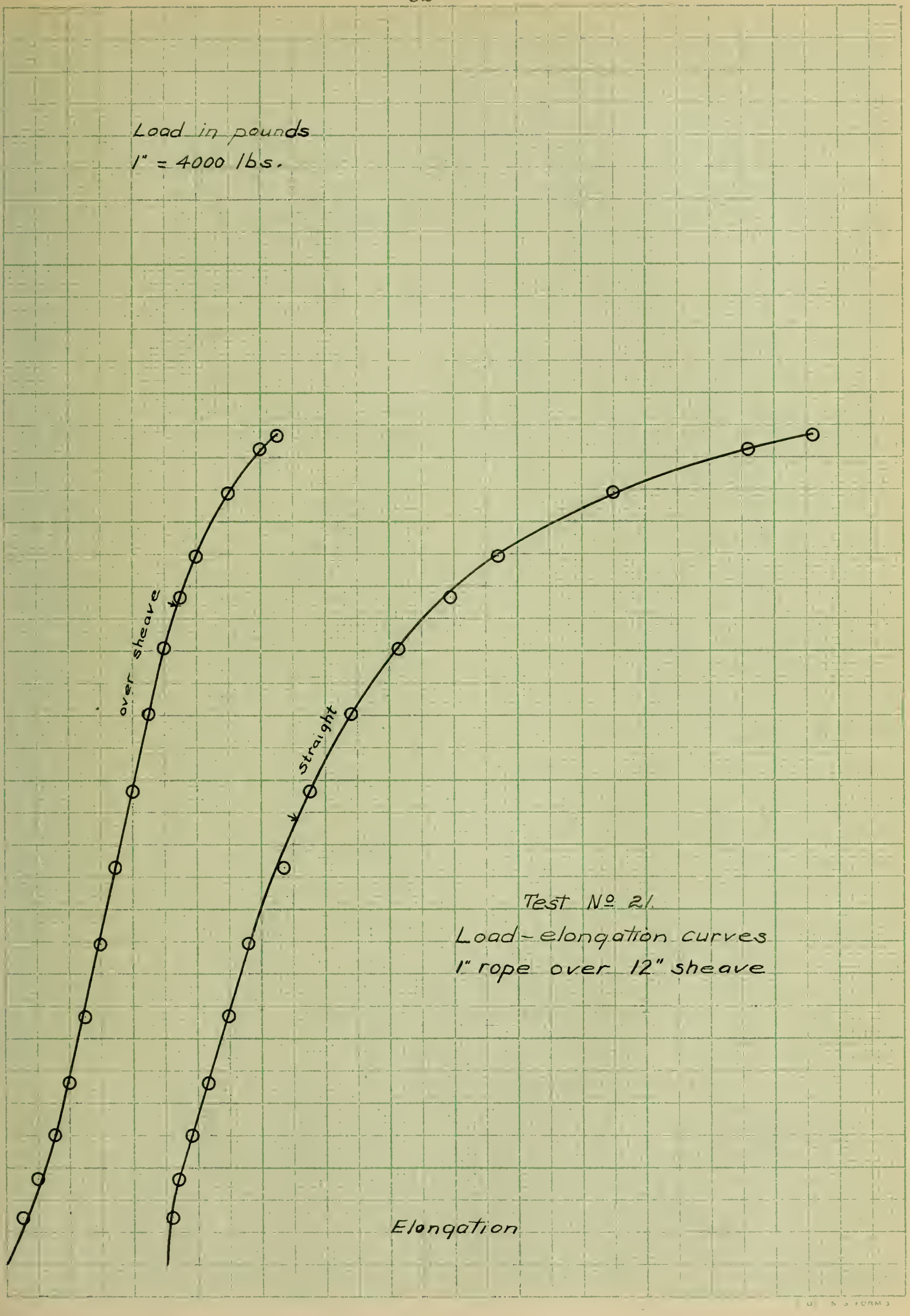

Load— 1" = 2000 lbs.
Straight
Over sheave
Test No 16
Load-elongation curves of
3/4" rope over 22" sheave.
Elongation.


Load — 1" = 2000 lbs.
Straight
Over sheave.
Test No. 17.
Load-elongation curves of
3/4" rope over 22" sheave.
Elongation.

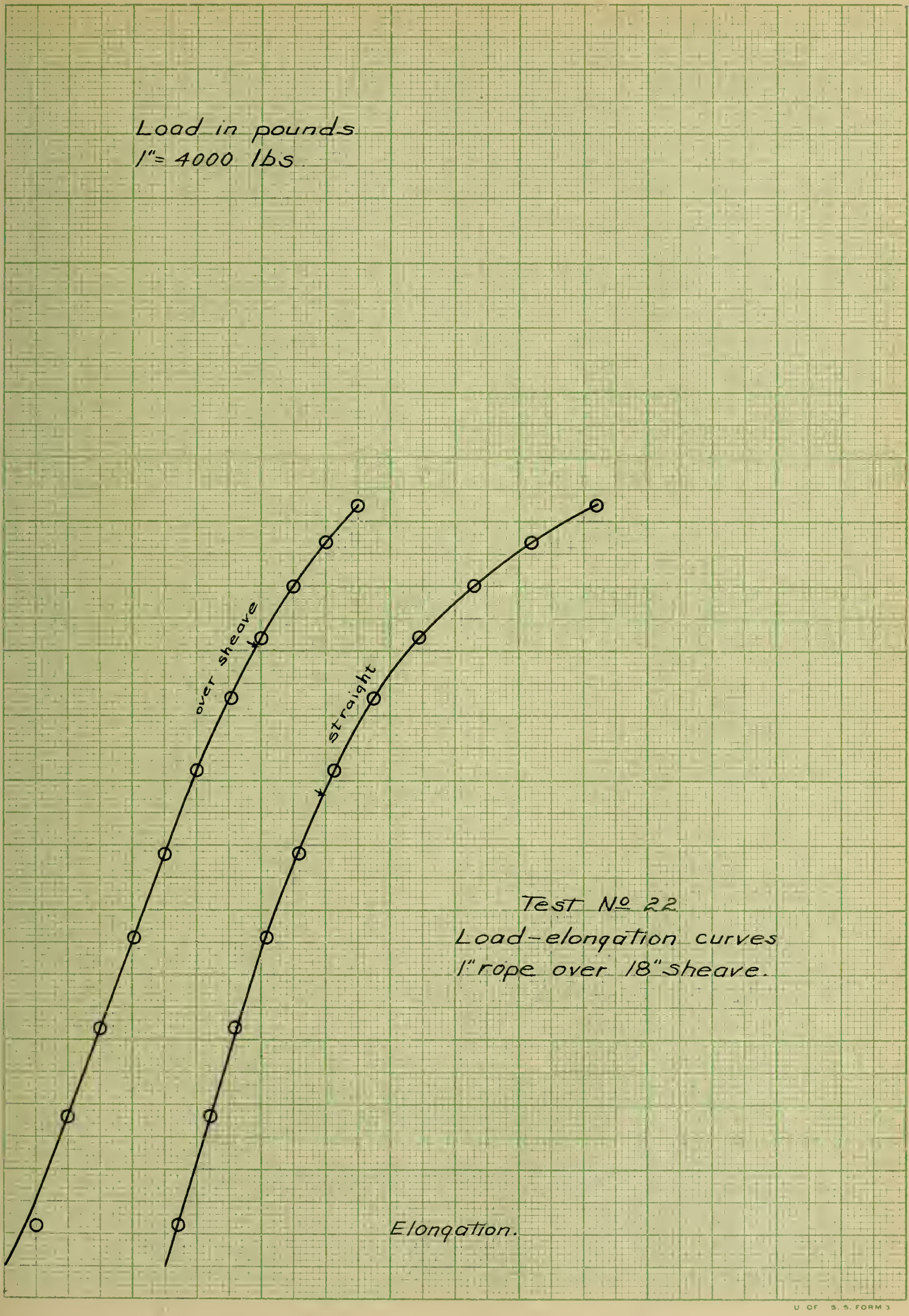

Load — 1" = 2000 lbs.
Straight
Over sheave.
Test № 18
Load-elongation curves of
3/4" rope over 22" sheave.
Elongation.

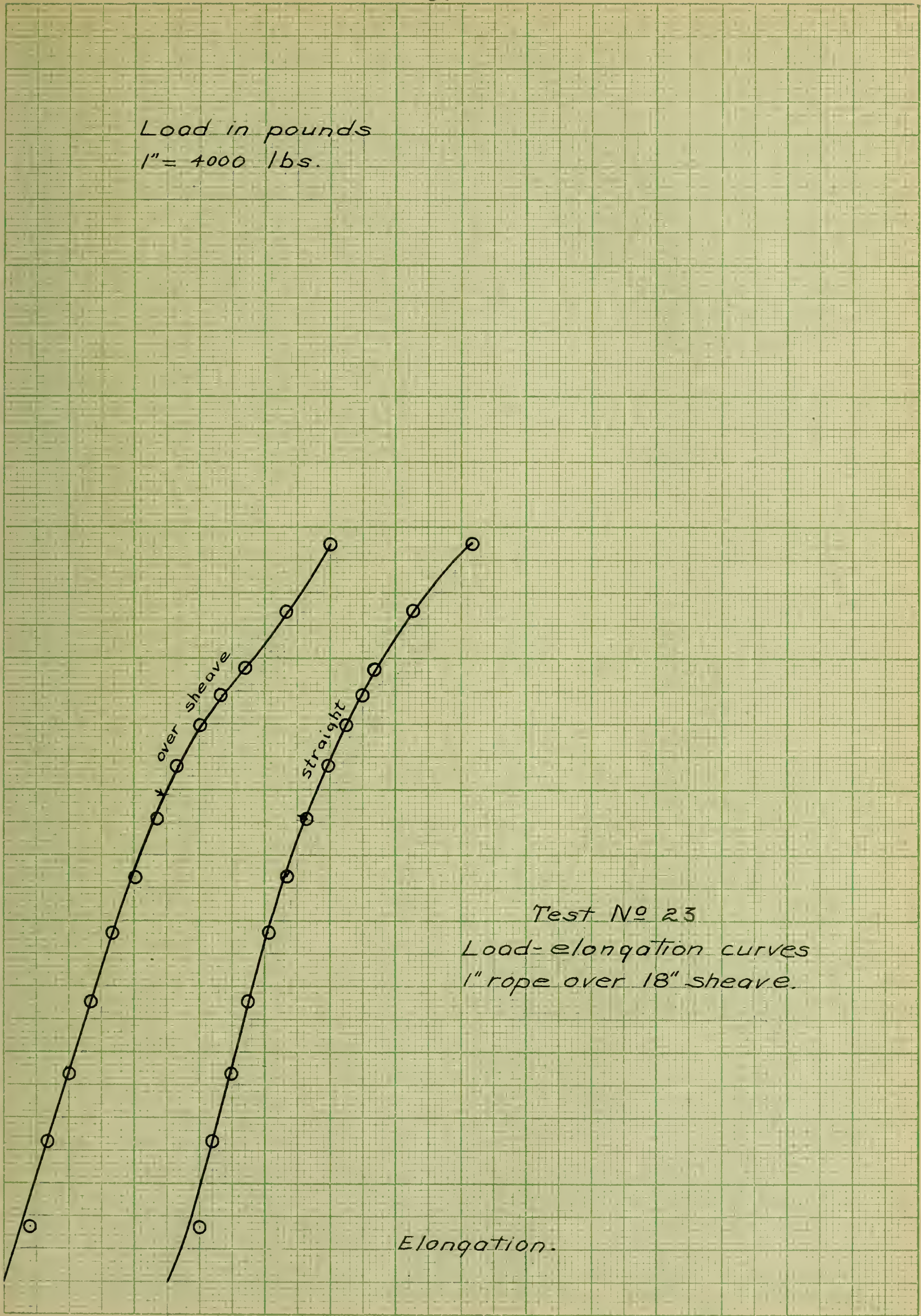

Load in pounds
1" = 4000 lbs.
over sheave
Straight
Test № 19
Load-elongation curves
1" rope over 12" sheave.
Elongation.

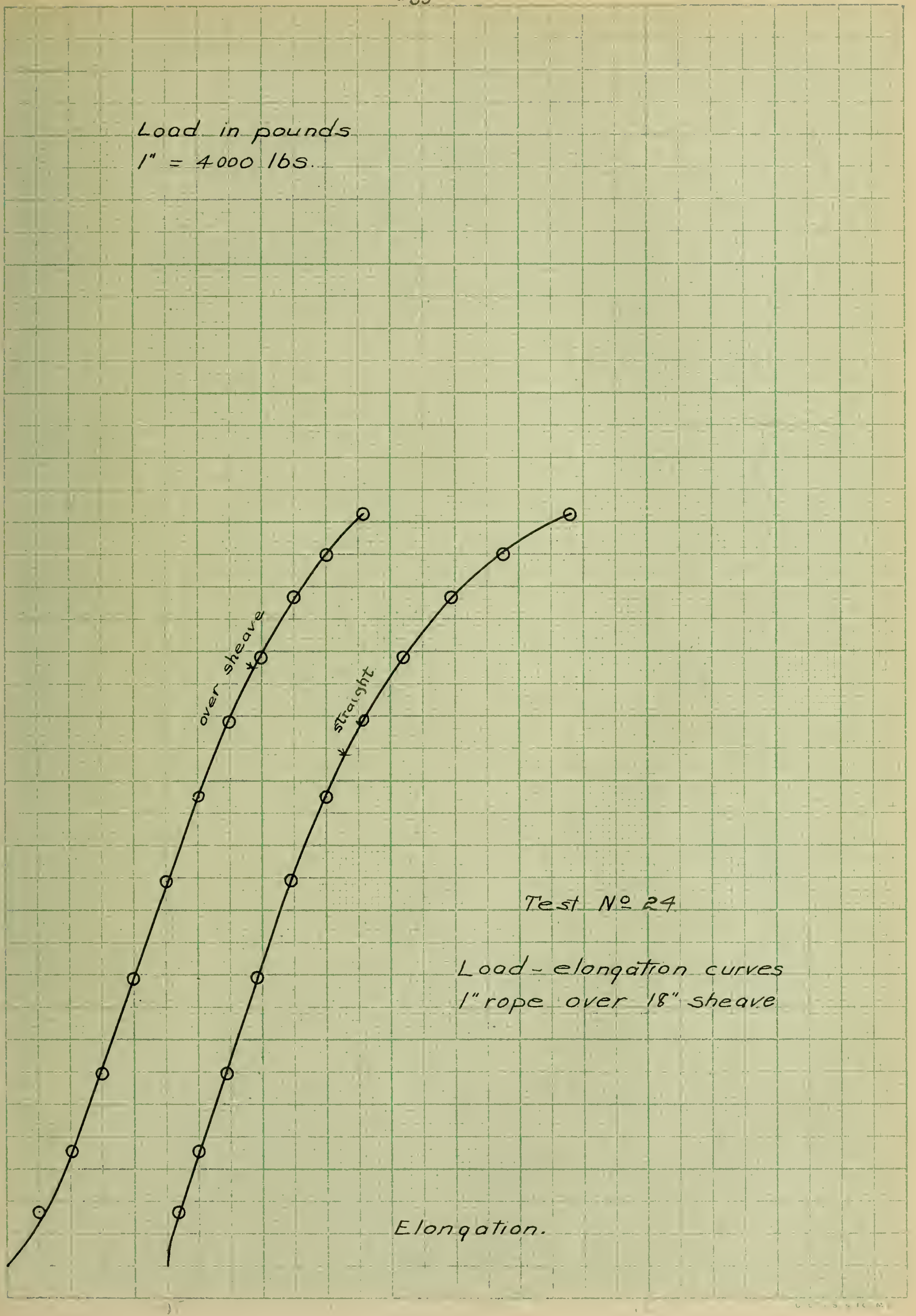

Load in pounds
1" = 4000 lbs.
over sheave
straight
Test No 20
Load-elongation curves
1" rope over 12" sheave
Elongation



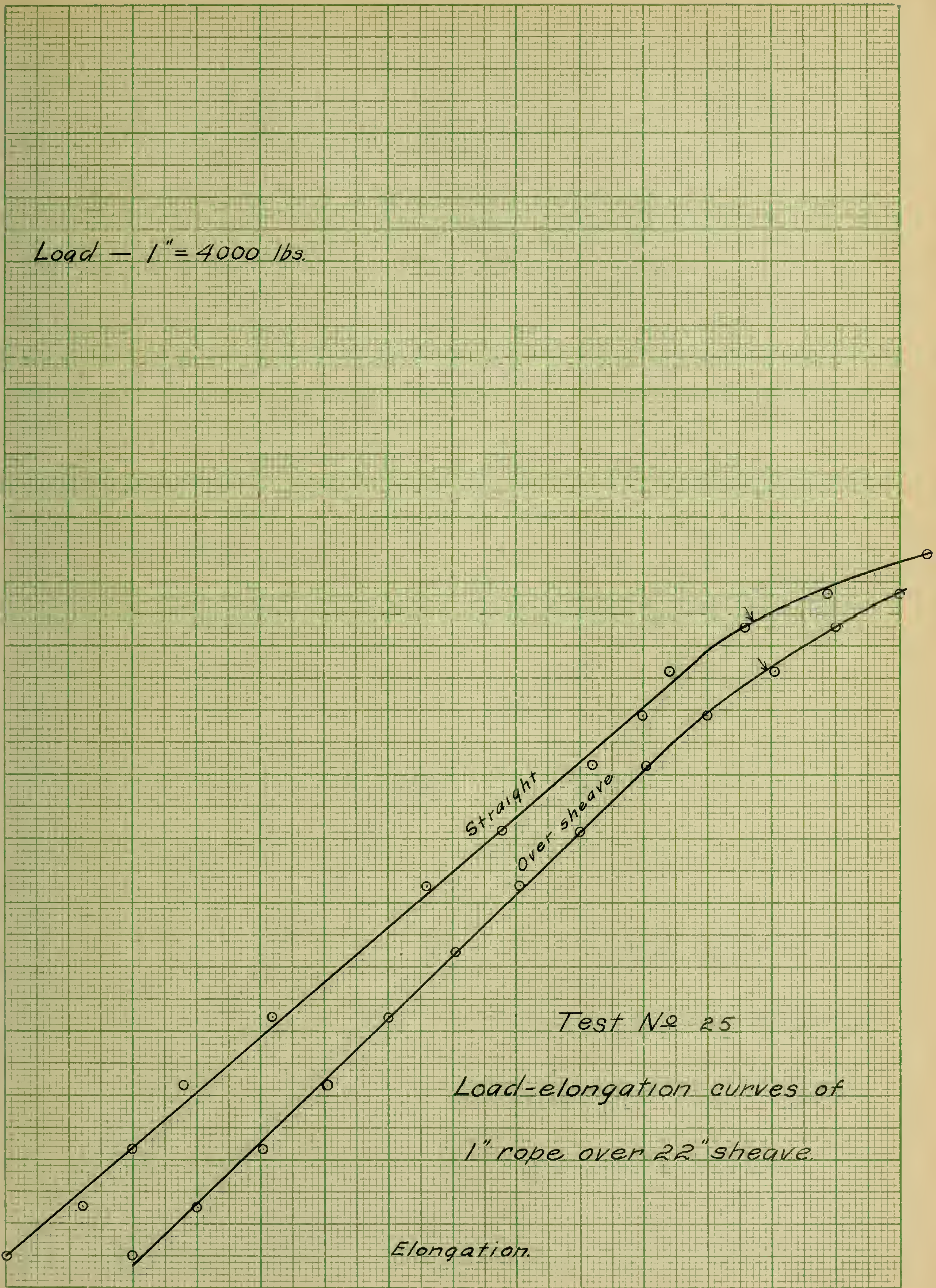
Test Nº 21
Load-elongation curves
1" rope over 12" sheave

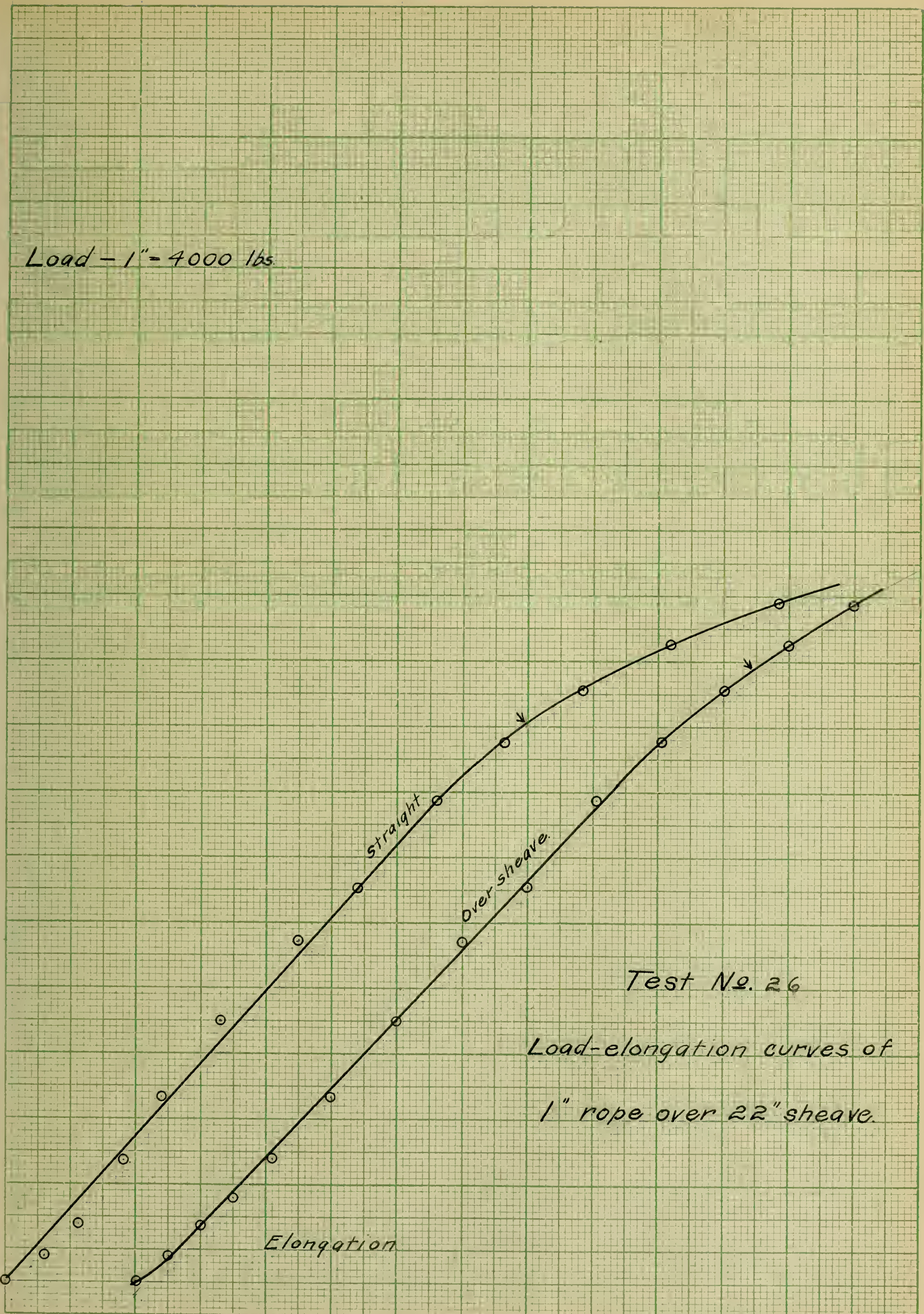

Load in pounds
1" = 4000 lbs
over sheave
straight
Test No 22
Load-elongation curves
1" rope over 18" sheave.
Elongation.


Load in pounds
1" = 4000 lbs.
over sheave
straight
Test No 23
Load-elongation curves
1" rope over 18" sheave.
Elongation.



Load in pounds
1" = 4000 lbs.
over sheave
straight
Test № 24
Load-elongation curves
1" rope over 18" sheave
Elongation.

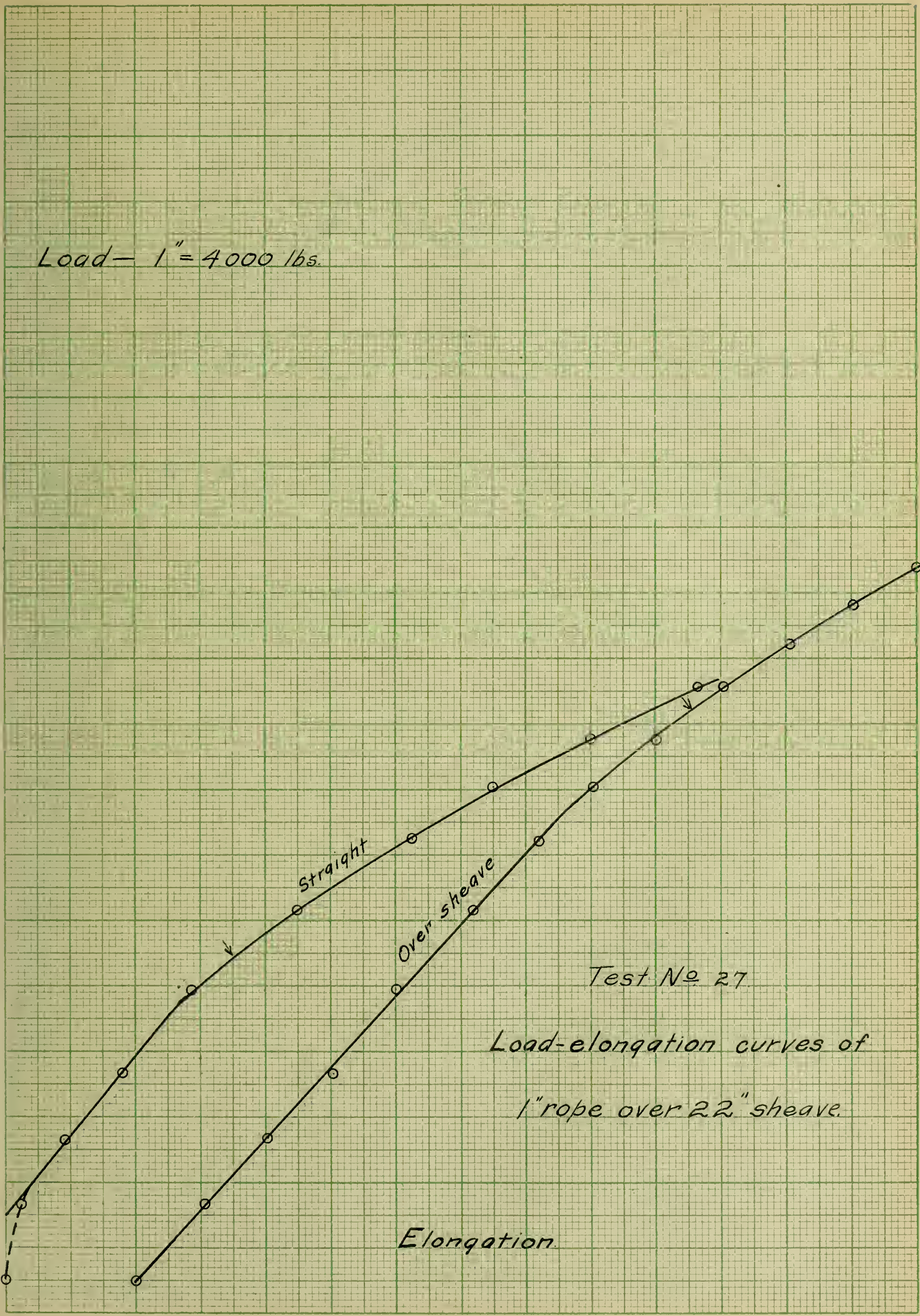

Load — 1" = 4000 lbs.
Straight
Over sheave
Test No. 25
Load-elongation curves of
1" rope over 22" sheave.
Elongation.

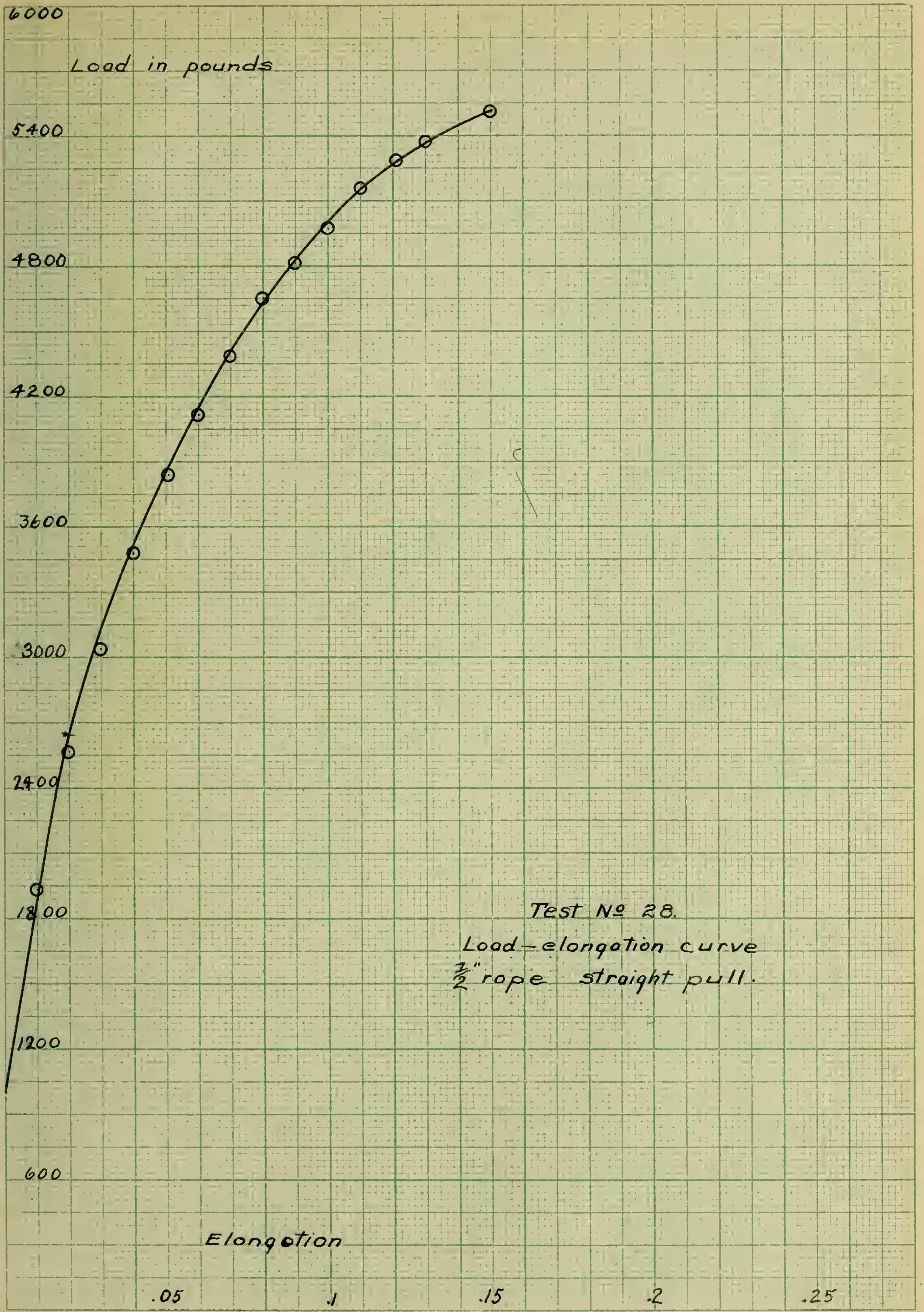


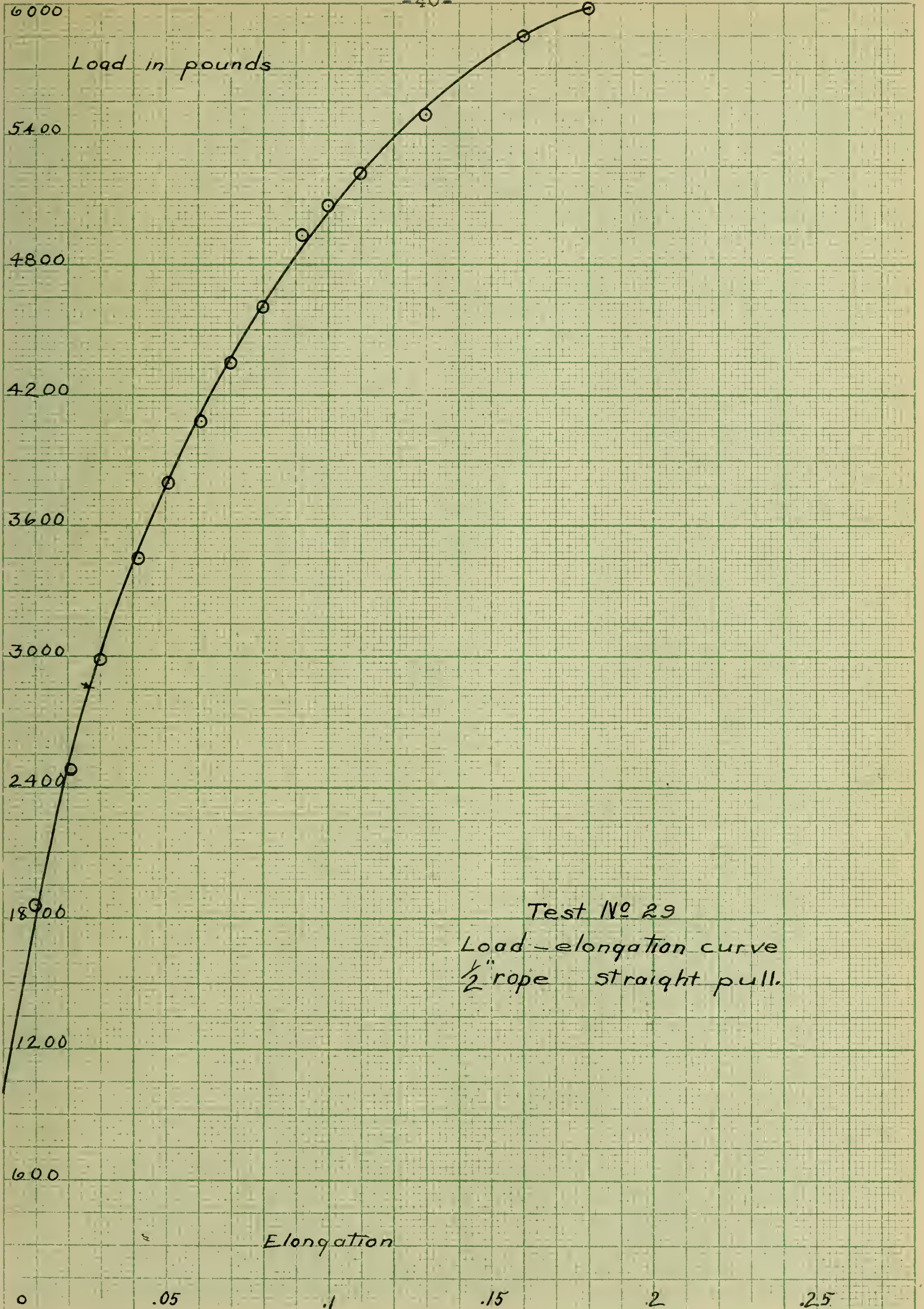
Test No. 26

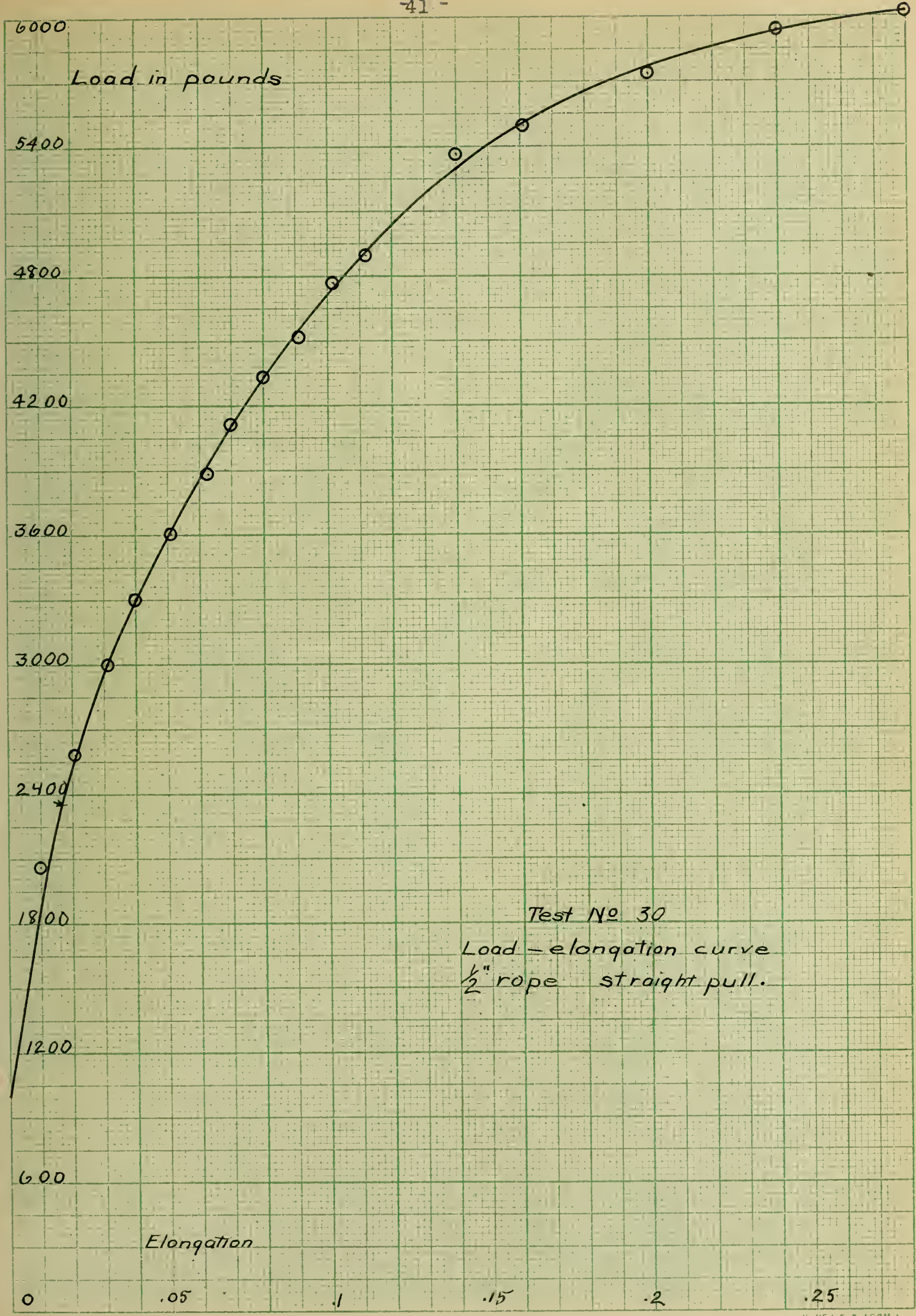
Load-elongation curves of

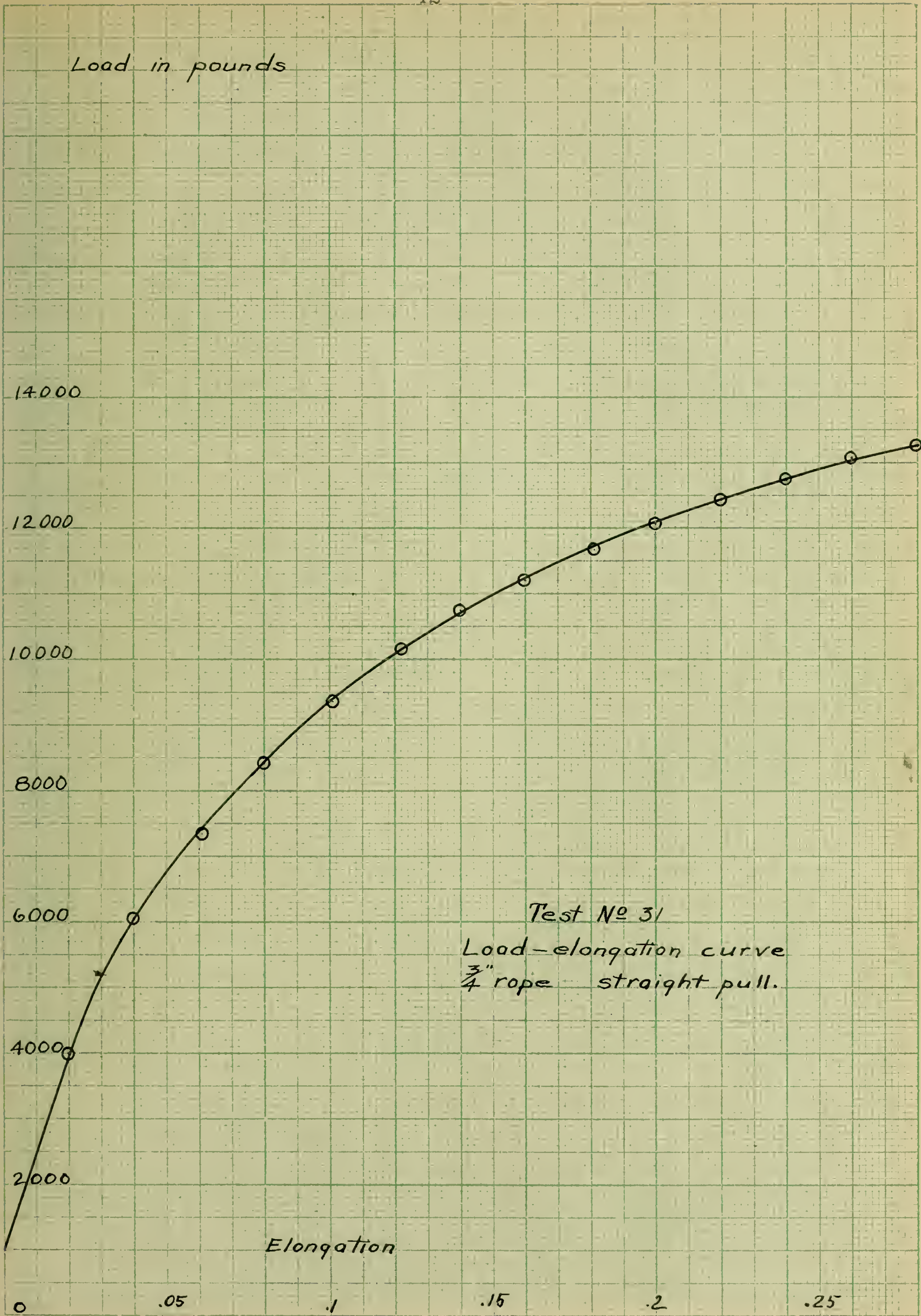
1" rope over 22" sheave.

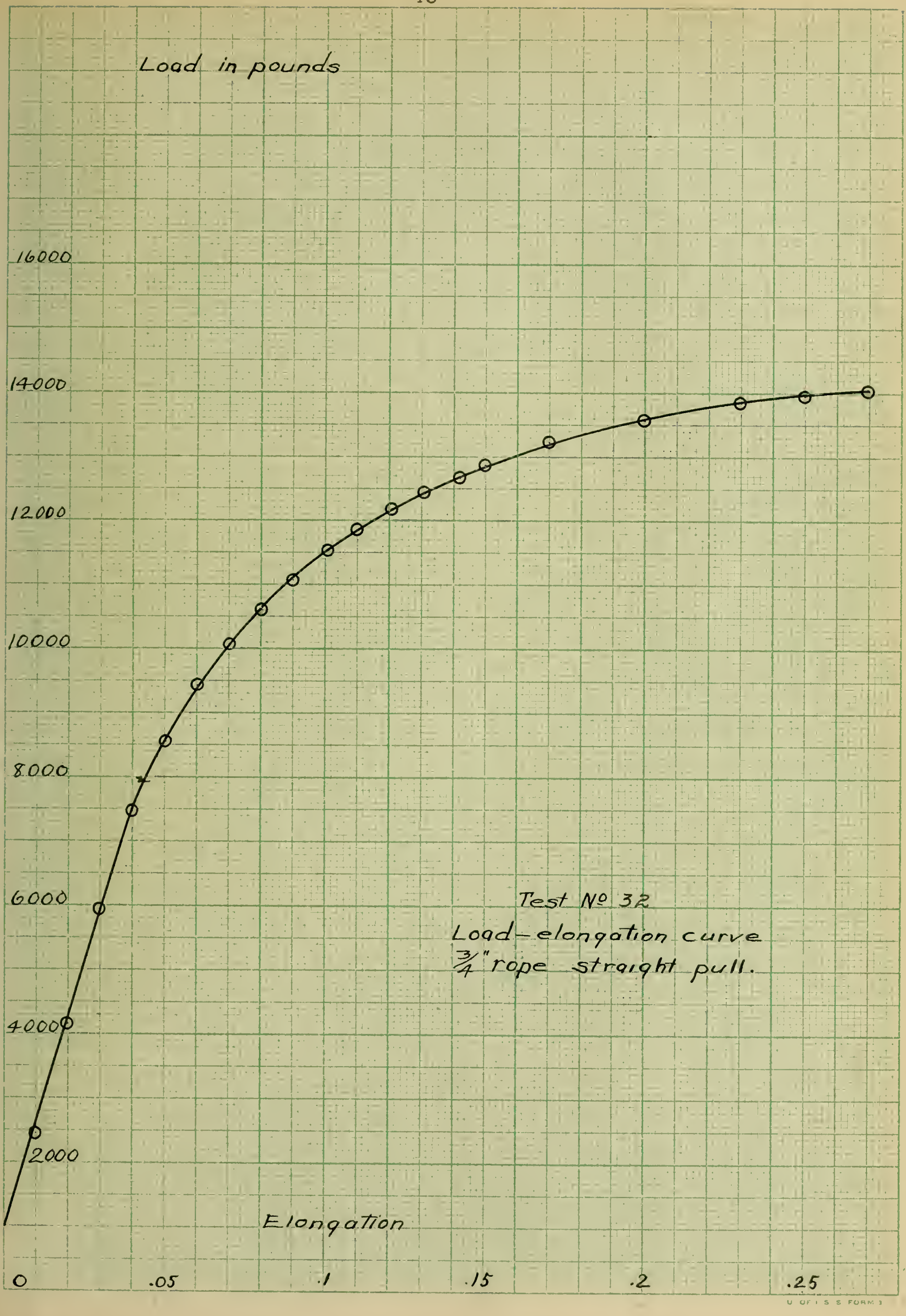

Load— 1" = 4000 lbs.
Straight
Over sheave
Test No. 27.
Load-elongation curves of
1" rope over 22" sheave.
Elongation.

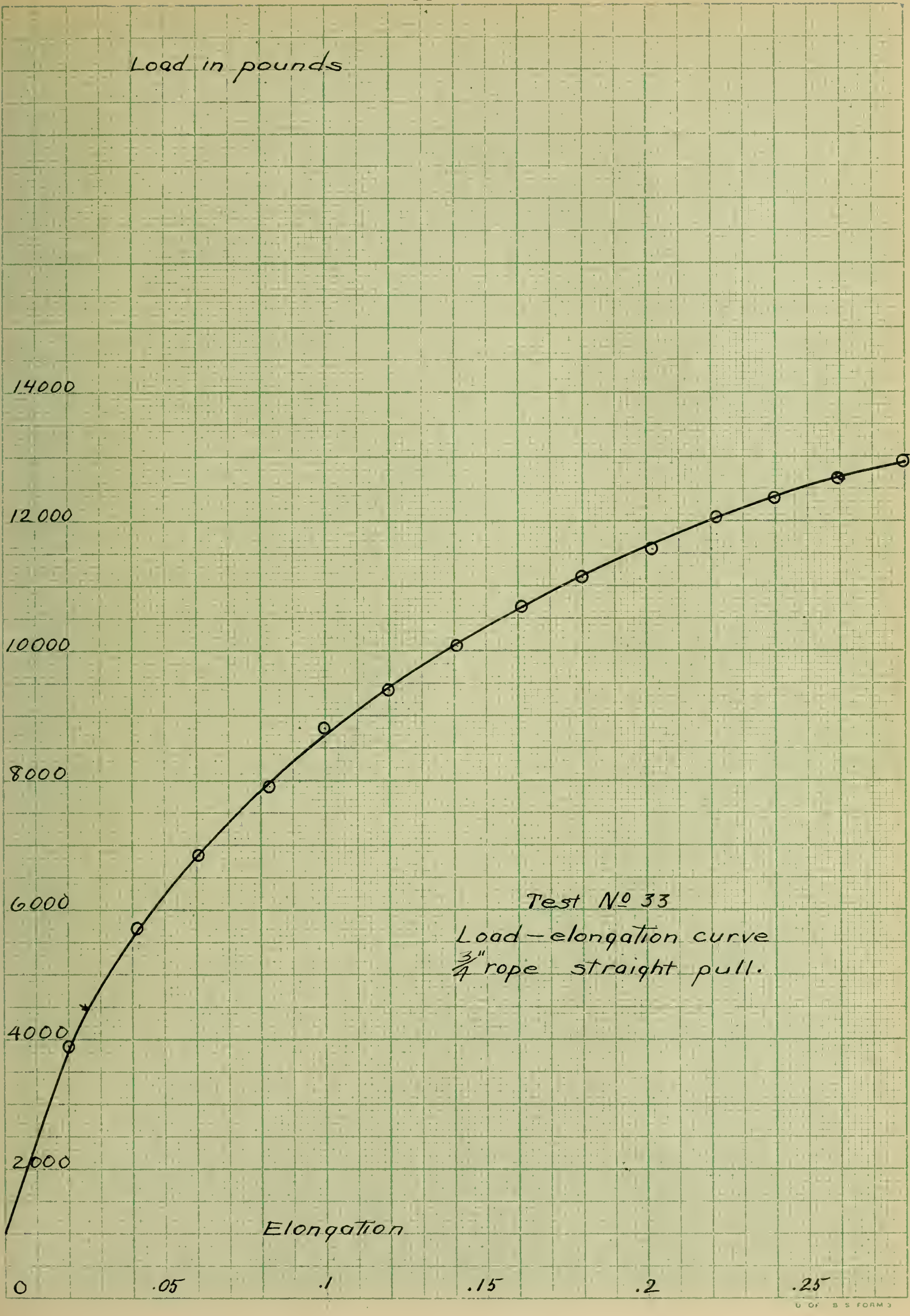

6000
Load in pounds
5400
4800
4200
3600
3000
2400
1800
1200
600
Test № 28.
Load-elongation curve
½" rope straight pull.
Elongation
.05
.1
.15
.2
.25

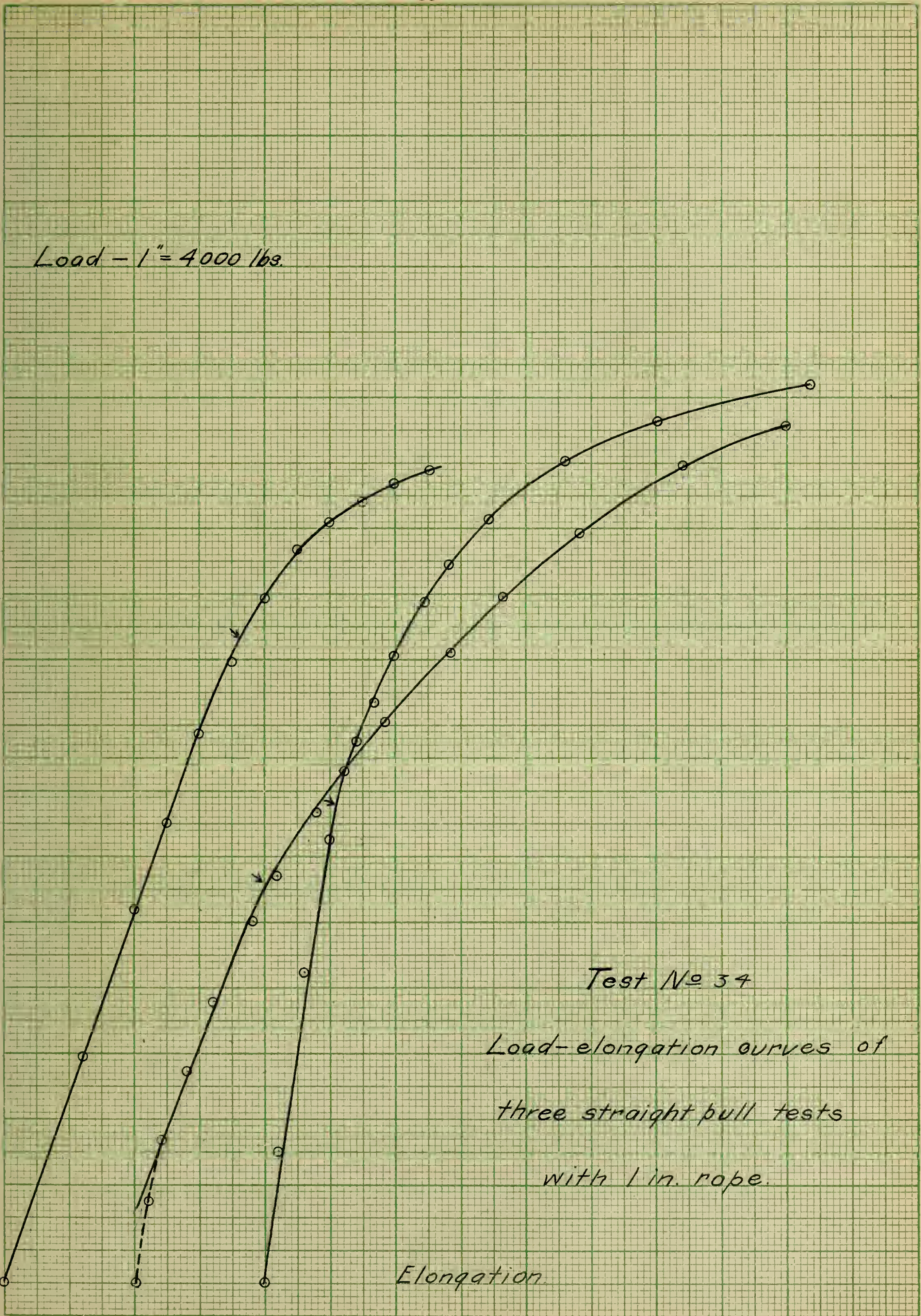

6000
Load in pounds
5400
4800
4200
3600
3000
2400
1800
1200
600
Elongation
0
.05
.1
.15
.2
.25
Test № 29
Load-elongation curve
1/2" rope straight pull.

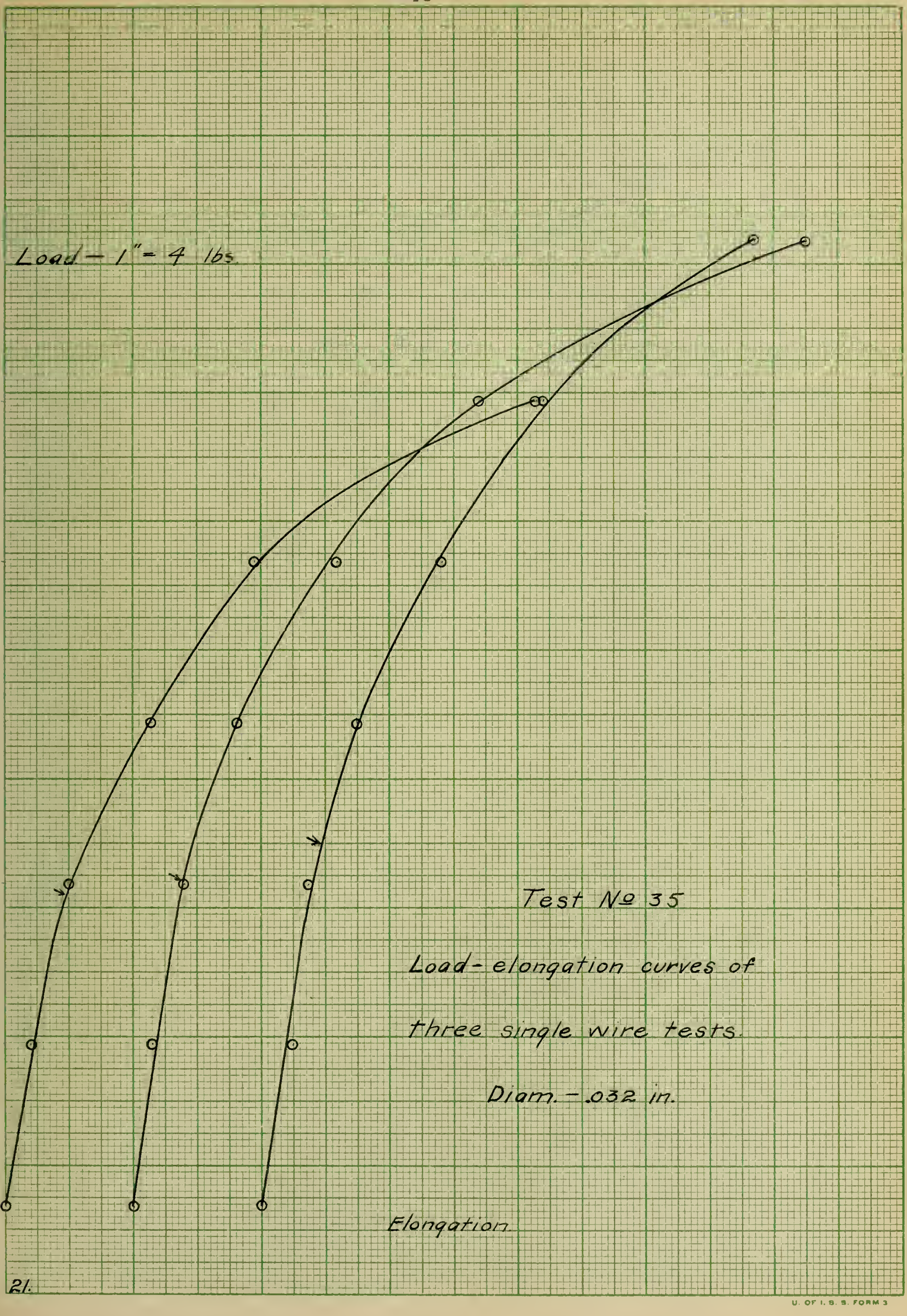

6000
Load in pounds
5400
4800
4200
3600
3000
2400
1800
1200
600
Elongation
0
.05
.1
.15
.2
.25
Test No 30
Load - elongation curve
1/2" rope straight pull.
U OF I. S. S. FORM 3

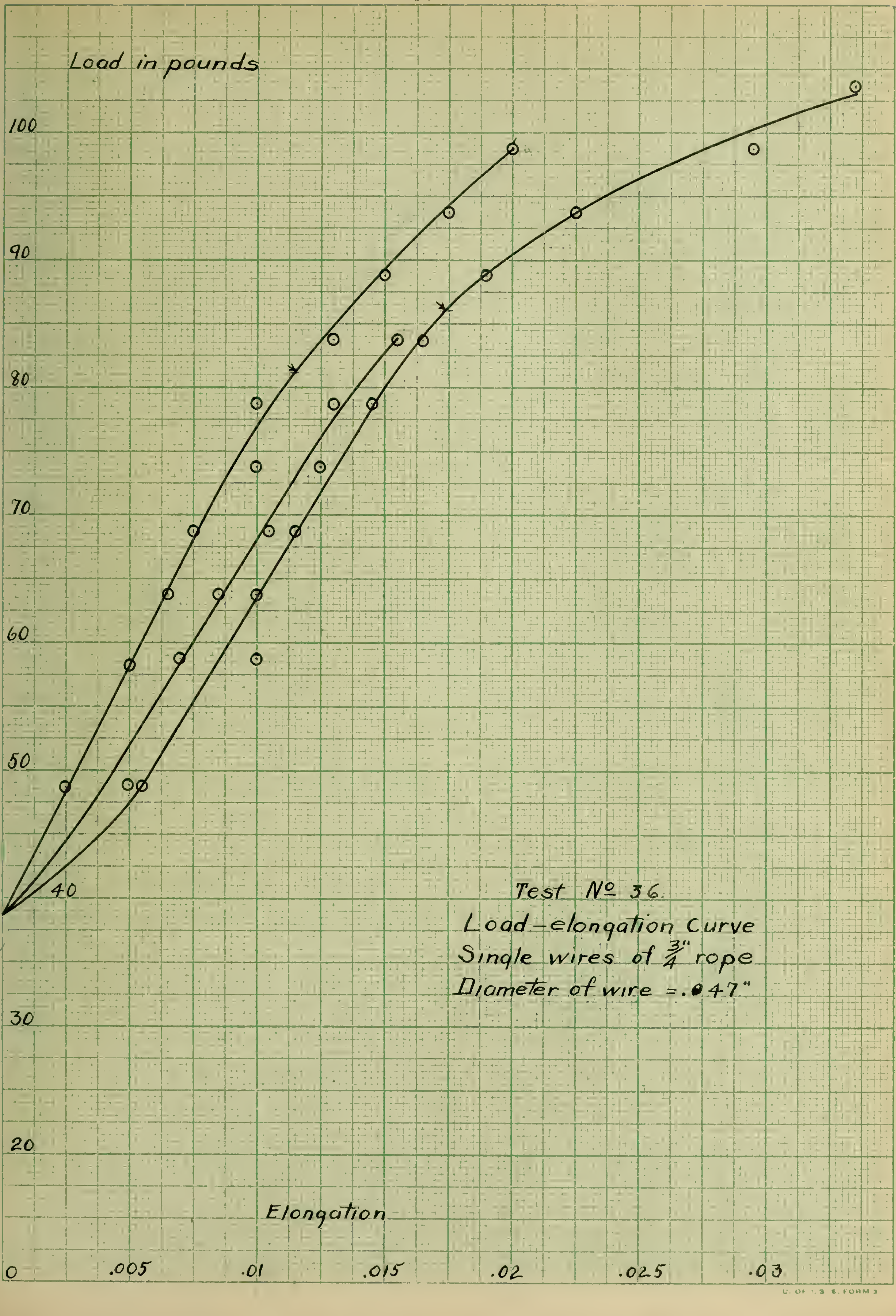

Load in pounds
14000
12000
10000
8000
6000
4000
2000
Elongation
0
.05
.1
.15
.2
.25
Test № 31
Load-elongation curve
3/4" rope straight pull.

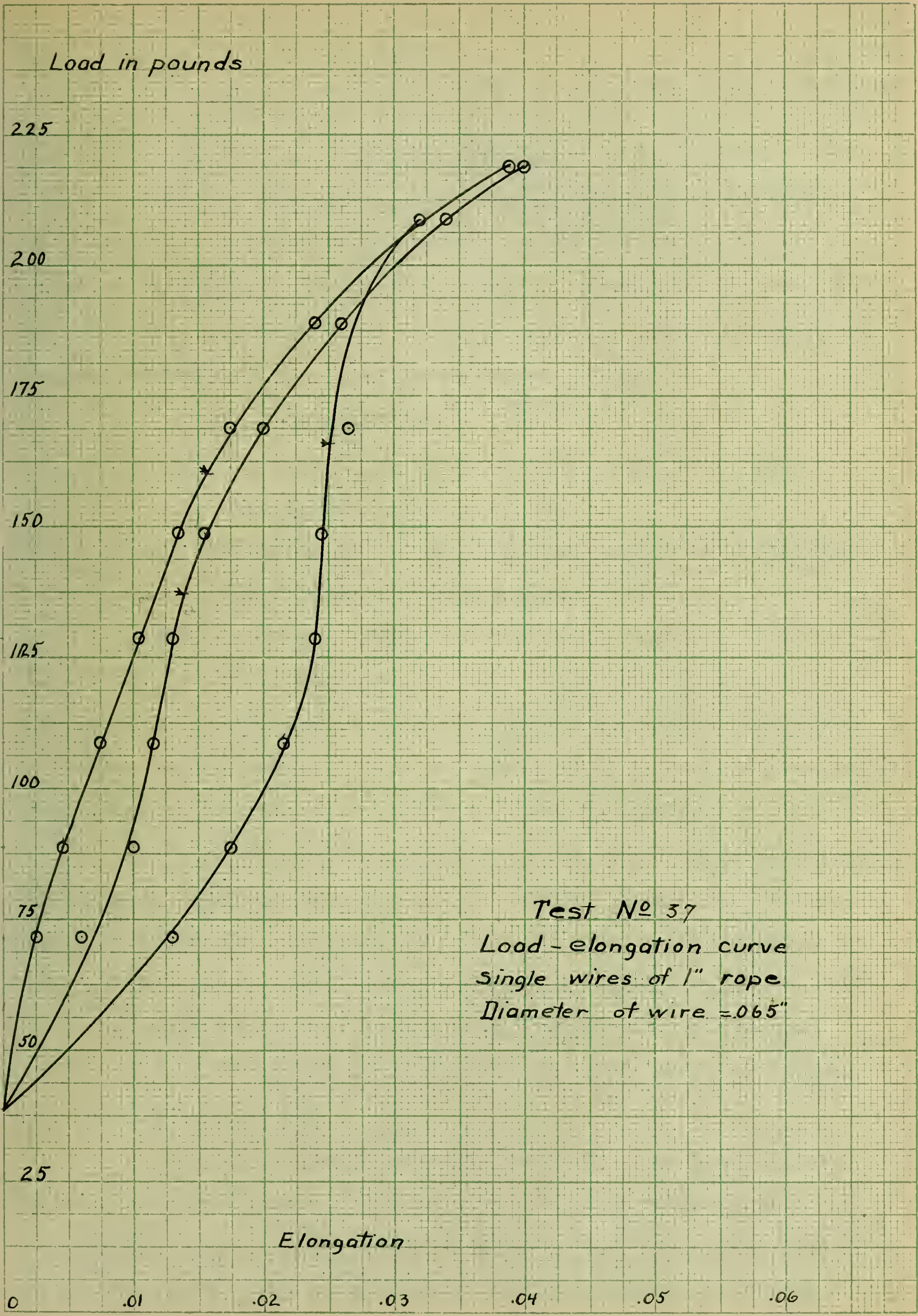

Load in pounds
16000
14000
12000
10000
8000
6000
4000
2000
Test № 32
Load-elongation curve
3/4" rope straight pull.
Elongation
0
.05
.1
.15
.2
.25


Load in pounds
14000
12000
10000
8000
6000
4000
2000
0
.05
.1
.15
.2
.25
Elongation
Test № 33
Load-elongation curve
3/4" rope straight pull.
U OF I S S FORM 3


Load - 1" = 4000 lbs.
Test № 34
Load-elongation curves of
three straight pull tests
with 1 in. rope.
Elongation.


Load - 1" = 4 lbs.
Test No 35
Load-elongation curves of
three single wire tests.
Diam. - .032 in.
Elongation.
21.


Load in pounds
100
90
80
70
60
50
40
30
20
Elongation
0
.005
.01
.015
.02
.025
.03
Test № 36.
Load-elongation Curve
Single wires of 3/4" rope
Diameter of wire = .047"
U. OF I. S. S. FORM 3


Load in pounds
225
200
175
150
125
100
75
50
25
0
.01
.02
.03
.04
.05
.06
Elongation
Test Nº 37
Load - elongation curve
Single wires of 1" rope
Diameter of wire = .065"

-IV-

DISCUSSION.

(16) The theoretical stresses set up in wire ropes due to bending are ordinarily determined by one of six formulas, namely: Reauleaux's, Hrabak's, Chapman's, Hewitt's, Sederholm's, or one by the American Steel and Wire Company. Each of these can readily be reduced to one of three simple forms:

$$\text{Reauleaux's, } S = \frac{Ed}{D}$$

$$\text{Hrabak's, } S = .44\,\frac{Ed}{D}.$$

$$\text{and, Chapman's, } S = .81\,\frac{Ed}{D}.$$

For a fuller discussion of the mathematical deduction, the reader is referred to the Coleman and Rugg thesis of 1910.

(17) Reauleaux considered a rope as composed of a bundle of single wires laid parallel, and based his discussion upon the assumption that each single wire acts as a simple beam under flexure. He made no allowance for angle of lay, which is a serious omission from the standpoint of a correct mathematical solution.

Hrabak found by experiment that a built-up rope stretched about three times as much as one of parallel strands and wires, and attributed the cause to the angle of lay. A mathematical investigation was then made which resulted in the formula $S = .44\frac{Ed}{D}$.

(19) To correct for angle of lay, Mr. R. W. Chapman applied a proposition in advanced geometry from which he derived his formula $S = .81\,\frac{Ed}{D}$.

(20) In getting a suitable formula to agree with the bending stresses determined from tests on plow-steel ropes, Coleman and Rugg arrived at one similar to the three just stated. It is $S = .15\,\frac{Ed}{D}$, and gives stresses which agree closely with

those actually found.

(21) Reference to the table of stress (Coleman & Rugg) computed by four formulas, including Coleman and Rugg's, shows in each case a theoretical stress much greater than the ultimate strength of the soft iron ropes used in the present tests. This alone would show that even though the angle of lay is provided for, these formulas do not hold for small sheaves, and moreover, an empirical formula, such as Coleman and Rugg's, holds only for ropes made of one kind of material, it being necessary to introduce new constants varying with the kind of metal in each rope.

(22) Assuming that the material is homogeneous throughout a given specimen, it is fair to say that any portion of the rope should show an elastic limit as soon as that part is stressed beyond a certain unit stress. That being true, the strength of a rope is directly proportional to the elastic limit.

(23) From the results of the soft iron rope tests no weakening due to bending stress could be detected. In every case the elastic limit for the part over the sheave was higher than for the corresponding straight part, and in turn, with but one exception, these elastic limits were higher than those given by the simple straight pull tests. This would tend to show that a rope is strengthened by bending it over a sheave,or that a negative stress results from the bending, which of course is absurd.

(24) The writers are unable to give an entirely satisfactory explanation for these negative results. However, several important features in conducting such tests have been considered and offer possible means of obviating negative results in further investigations.

(25) FASTENING ROPES IN SOCKETS: It is evident that no wire rope can be so fastened in a grip that each wire will be equally stressed the instant a load is applied. The load must therefore be unequally distributed. Since the specimens tested were short, it is likely that some of the wires were excessively stressed throughout their entire length. In the case of ductile material, like soft iron, the wires stressed first stretch readily, then others are gradually brought into service until each one carries a part of the load. A load-elongation curve under such conditions has no straight part at the beginning as it would have if all the wires were stressed equally and the elongation varied directly with the load. This is identically what happened in several instances, especially with the smallest size of rope. In such cases the curves show no distinct break and an accurate elastic limit would not be defined. In fact it was almost impossible to accurately determine the elastic limit in any case; Johnson's method, however, was used (see page 8) and gave results that were consistent throughout all the tests.

The soft iron ropes were fastened into sockets at the University by a man of some experience in repairing hoisting ropes for mining purposes. It is probably that if fixed by the company furnishing the ropes, the work would have been done by an expert of more experience, consequently they would have been able to withstand a greater load. Under these conditions the ultimates are not so reliable as they would otherwise have been, and cannot be used as a basis for comparisons or for forming con-conclusions. It is not likely that the elastic limits would be so materially affected by faulty fastening in the sockets as the ul-

timates, and for that reason are considered of the greater value in the results of these tests.

(26) TWISTING OF THE ROPES: It was observed that the extensometers turned in a horizontal plane through an angle of about 90 degrees from their first position during each test; at the same time the strands unwound through an equal angle. If the ratio of twist to load remained constant throughout each test, the twisting had no effect upon the load-elongation curve, but if the ratio increased with the load, the apparent elongation was greater than the actual, and the elastic limit was decreased accordingly. Since no record was kept of the rate of twisting, no correction could be made.

(27) As another possible explanation for negative resutls, friction in the bearings might very well be considered. For friction to have any effect upon the elastic limit of a specimen it must first be assumed that the maximum stress need not come at the point of contact, as will be explained later, but rather somewhere farther up on the sheave. The load on the beam of the testing machine measures the stress in the straight part, while the stress over the sheave is made up of the load plus the stress caused by bending. The friction force on the journal acts against the load making the actual stress over the sheave less than the apparent. To get the actual elastic limit over the sheave the friction force, or some part of it, must be subtracted from the load. In each case where the proper friction force was subtracted a reasonable bending stress appeared.

(28) In a preceding paragraph it was stated that as soon as any portion of the rope between the limits of the extensometers

is stressed beyond the elastic limit there should be a corresponding break in the curve. Theoretically the place where an excessive stress should occur is at the point of contact with the sheave. It is believed by the writers that this is not necessarily true for a built-up wire rope of ductile material. An examination of a rope over a sheave shows that no two strands are bent in equal arcs at the same cross section. It can also be seen that one strand, carrying an excessive load, is bent in a small arc at one place and a few inches from that place it is straightened out to its normal position, or possibly bent in the opposite direction. Again, the outermost fiber at the point of contact becomes the inner fiber a little way from that point, while the same fiber may be on the opposite side of the rope at the grip. The fiber apparently in a position to be stressed most may be sufficiently lengthened by the angle of lay of the strands to counteract the bending stress entirely. Since bending over a sheave is so slight compared with that caused in the manufacturing process, and since the elastic limit is exceeded so many times during the process, it is believed that the static strength of a soft iron wire rope is not materially changed by bending over a sheave.

(29) When a wire is drawn to its proper size in the wire mill, there is an outer layer or hard, brittle crust formed that is much stronger than the metal at the center, in other words the wire is no longer homogeneous, and actual fiber stresses caused by bending cannot properly be figured on the basis of the elastic limit.

-IV-

RESULTS.

(30) In each test the elastic limit over the sheave is higher than for the simple straight pull tests of the same size rope, and again, it is higher than for the single wires, showing conclusively that the ropes were not weakened in static strength by bending over sheaves. These results indicate that for soft iron ropes stresses due to bending over sheaves of the smallest size common in crane or electric service are negligible.

(31) The cutting action of wire on wire is not so severe as it is for ropes of harder material. Since new ropes are well lubricated, friction between wires is reduced to a minimum, and they can move freely past each other as they are stretched. In ropes of soft material this stretching is much more than in ropes of hard material, and even though nicking is not so deep as for hard material, it is distributed over more area and is quite as severe when the life of the rope is considered.

(32) The average ratio of simple straight pull elastic limits to the elastic limits of corresponding single wires was found to be seventy-four percent, which is slightly lower than the value generally given. The ratio of ultimates proved to be considerably higher.

(33) The ultimates varied so widely and depended so much upon fastening in the sockets that they were not considered in drawing conclusions.

Coleman and Rugg give the following factors upon which static stresses depend:

Kind of material.

Diameter of single wires.

Diameter of strands.

Diameter of rope.

Diameter of sheave.

Number of wires.

Number of strands.

Modulus of elasticity.

Friction between wires, or stiffness.

Speed of bending.

Length of wires in the length of strand.

(34) From the enumerated results it is seen that stresses caused by bending depend upon so many factors that computed stresses can be more accurately made from empirical formulas than from those of purely theoretical derivation. Since no bending stresses were found in the present tests, no empirical formula could be made.

—VI—

CONCLUSIONS.

(35) Static bending stresses in wire ropes of ductile material bent around small sheaves are negligible.

(36) Static bending stresses in plow-steel ropes bent around sheaves are small, and are not so important as the wear of wire on wire.

(37) The proper sizes of ropes and sheaves for actual service should be figured by a formula based upon tests made under actual working conditions, in which wear and reversed bending occur.